Effects of Animal Behavior and Core-Body Temperature on Production Efficiency of Grass-Finished Beef Cattle.

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Dedication

I would like to dedicate this thesis to my grandma, Aloha Stevens, who lived up to her name every day of her life. Thank you, grandma, for teaching me that even the toughest challenges in our lives can be blessings and to always love with your whole heart. I will forever be thankful that the Lord blessed me with you as my grandma. I miss you and love you with all my heart.

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Abstract

Forage nutrient quality and consumption have major impacts on ruminant production. Energy requirements of the grazing animal are influenced by several factors such as increased foraging activity, frame size, and physiological status, but is superseded by the requirement to maintain a homeothermic balance. Therefore, we hypothesized that changes in grazing behavior activities would affect core-body temperature (CBT) and animal performance measures. A two-year study utilizing two cohorts of 24 grass-finished cattle at the University of Hawai‘i, Mealani Agricultural Experiment Station. Animal behavior, CBT, weather variables, and forage quality were assessed during three, daily observation periods (AM, NOON, PM), for fall 2013, and summer and fall 2014 seasons. Over all seasons, active grazing (63.0%), standing (15.6%) and laying while chewing (10.4%) were the predominant behaviors observed. Grazing activity across daily periods was highest during the AM period, a time when mean CBT (38.3±0.01°C) was lowest. The CBT varied for all animals across seasons and periods and averaged 38.6 (±0.03) °C in 2013 and 38.4 (±0.04) °C in 2014. We did not find any significant relationship between CBT and grazing behavior. Forage quality varied seasonally, however crude protein (CP), and total digestible nutrients (TDN) were higher in summer 2014 compared to the fall seasons. Diurnal differences were observed in water-soluble carbohydrate (WSC) and non-fiber carbohydrates (NFC), which were higher in the PM across all seasons. Average Daily Gain (ADG) was not significantly different (P=0.78) between the years 2013 (0.87±0.04 kg/d) and 2014 (0.84±0.03 kg/d). Animals were slaughtered at approximately 21 (± 0.15) months of age and had an average live body weight of 527.1 (±8.98) kg in both years. In 2013, 75% of the animals graded Choice or higher compared with 90% in 2014.

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Introduction

Currently, about 70% of Hawaii born calves are shipped to mainland feed yards for finishing due to the high cost of shipping feed into the islands (USDA-NASS, 2013). Producers have found that it is more cost effective to ship weaned calves via air or ocean freight to mainland markets or feed yards than to import grain for finishing cattle in Hawaii.

One advantage that Hawaii livestock producers enjoy is the ability to graze animals on quality forage all year long. This is the result of advantageous climatic influences that allow for favorable forage growing conditions throughout the year. Warmer temperatures along with adequate precipitation promote greater production of quality forage when compared to temperate regions. In a recent study, Fukumoto et al. (2015) identified suitable zones for grass-finished beef production in Hawaii. They found that of the 801,693 acres of pasture and rangelands in the state, 65% were of suitable quality for finishing beef on forage.

The grass-finished beef diet is composed solely of grasses and other forages (i.e. legumes) from birth through their finishing phase as compared to cattle finished in a feed-lot. In a feedlot, cattle are finished on a diet with a larger proportion of high-energy concentrate feeds, such as corn, grains (wheat, barley, etc.) and/or distiller's byproducts, than of roughage feeds, such as grass-hay or silage, typically in the last 90 – 120 days before slaughter. The high-energy concentrate feed offers a consistently high level of nutrition for cattle, compared to an all-forage diet of grass-fed cattle, which may be lower in energy and variable in quality and quantity. Thus, feedlot-finished cattle reach target slaughter weights at a younger age than grass-finished cattle. However, grass-finished beef production may be more sustainable in areas where forage quality and quantity is more reliable and a grain-fed diet is costly or unavailable.

Variability in the quality of meat of grass-fed beef is greatly influenced by diet, age, and genetics. Meat quality refers to the palatability (juiciness, flavor, appearance, and tenderness) and composition (water, protein and amino acids, minerals, fats and fatty acids) of the meat. These elements are the major factors consumers use to evaluate the eating quality of meat (Maltin et al. 2003) and they are highly influenced by the animal's diet and age (French et al. 2000a; 2000b; Huuskonen et al. 2010; and, Jiang et al. 2010). Juiciness and flavor tend to fall lower in the consumers purchasing cues, likely due to changes that occur with cooking style, while appearance and tenderness tend to be greater influences (Troy and Kerry 2010). Appearance is associated with "freshness" and is the first quality attribute assessed by consumers making a purchasing decision (Troy and Kerry 2010). Age directly affects meat tenderness due to the natural occurrences of collagen, an abundant connective tissue protein that increases with age (Weston et al. 2002). Controlling the age at slaughter (Kim et al. 2007) and post-slaughter techniques such as needling and electrical stimulation (Troy and Kerry 2010), in addition to post-slaughter processes like aging and hanging, are methods to improve meat tenderness. Tenderness is highly regarded by the consumers as the predominant determinant of meat quality (Maltin et al. 2003; Troy and Kerry 2010) and is easily evaluated with shear force techniques (Koohmaraie and Geesink 2006). Studies have found that consumers are willing to pay a premium for beef that is certified tender (Miller et al. 2001; Xue et al. 2010; Troy and Kerry 2010). The lower fat content in grass-fed beef can lead to a decrease in tenderness due to the lack of intramuscular fat (Jiang et al. 2010). Additionally, forage-based diets result in higher levels of beta-carotene in the fat than found in beef from feedlot finished animals. Beta-carotene causes a yellow coloring in the fat that is perceived as an unpleasant appearance by consumers thereby affecting the quality of the product (French et. al., 2000a).

Over the years the health benefits of grass-finished beef have gained popularity with consumers across the mainland US as well as in Hawaii. The composition of grass-finished beef is considered to be healthier than feedlot-finished beef because of its lower overall fat content, higher levels of healthy fatty acids (omega -3 & conjugated linoleic acid) and cancer-fighting antioxidants (Daley et al. 2010). This is because the high-concentrate diets of feedlot beef result in high amounts of saturated fatty acids (SFA) and an unbalanced ratio of omega-6 to omega-3 (n-3: n-6) polyunsaturated fatty acids (PUFA) (Daley et al. 2010, Razminowicz et al. 2008; and French et al. 2001) relative to beef from animals on all forage diets. Dierking et al. (2010) found that forage diets high in clovers increase the production of CLA due to a substance called polyphenol oxidase (PPO) that protects PUFA allowing it to bypass the rumen and be absorbed in the lower gastrointestinal tract.

Through the process of photosynthesis, plants capture solar energy to convert CO_2 into carbohydrates (CHO) that are subsequently used for tissue growth, metabolic processes, and energy storage. Studies have found that accumulation of CHO in the plant increases during the day, thus resulting in higher CHO levels in late afternoon or evening periods compared to morning periods (Fulkerson & Donaghy 2001; Haydon et al. 2013; Moraes et al. 2012; Shewmaker et al. 2006; White 1973). In a study by Gregorini et al. (2006a), animals in the afternoon period grazed longer and with greater intensity compared to earlier in the day. The nutritive value of a plant has been found to be positively correlated with diet selection (Burns and Sollenberger 2002) while increased CHO has been correlated with increased dry matter intake (Huntington and Burns 2007). However, the increase in activity due to longer grazing bouts may have a higher energy cost for the animal.

In a study by h et al. (2006), they suggested that locomotion during grazing has an energy expenditure of 8.5 to 16.5 % above maintenance levels. Grass-finished cattle need to travel greater distances to graze sufficiently to meet their nutritional requirements compared to those in a feed-lot system. Frame-size may also influence activity cost because a large-framed animal will have greater nutritional requirement compared to small-framed counterparts. Based on total energy cost, Aharoni et al. (2013) reported that smaller framed cattle are more energy efficient by means of locomotion and use this advantage to select forage of higher quality and digestibility. In addition, the increase in activity during the foraging period coupled with environmental stresses can alter core-body temperature (CBT) (Aharoni et al. 2013; Gebremedhin et al. 2011). Core body temperatures elevated above normal (36.7-39.1°) are associated with heat stress that can lead to decreased dry matter intake (Morrison 1983; Huston and Pinchak 1991). This is due, in part, to two mechanisms. First, during a heat stress bout, nutrient partitioning shifts in favor of the thermoregulatory mechanism of the body (O'Brien et al. 2010). Secondly, heat stressed cattle will alter behavior to alleviate heat through various methods that reduce grazing time and forage intake.

The interactions between grazing behavior, forage quality, and CBT may influence the production efficiency of grass-finished beef. The nutritive value of forages consumed in a grass-finished program should meet the nutrient requirements of the physiological stage of the animals consuming the forage. Grass-finished beef has many positive human health attributes, but there are challenges and concerns about key meat quality factors (tenderness, yellow fat). It is important for grass-finishing beef programs focus on efficiently producing high-quality beef with a high level of acceptance by consumers.

The goal of this study was to evaluate the effects of grazing behavior and core body temperatures on the productivity of grass-finished beef cattle. Therefore, we hypothesized that changes in grazing behavior activities would affect core-body temperature (CBT) and animal performance measures. Thus, thermally stressed cattle would have reduced grazing bouts that effect performance and production capacity. The objectives of this study were to (1) measure core-body temperature and grazing animal behavior of grass-finish beef cattle on pasture (2) evaluate the influence of ambient weather conditions and forage quality on animal performance (Average Daily Gain), and (3) determine if animal performance affected carcass traits and meat tenderness.

Literature Review

Meat Quality

Consumers are willing to pay a premium for good-quality grass-fed beef (Miller et al. 2001; Cox and Bredhoff 2003). However, the variability in quality of a forage-based diet can lead to slower rates of gain and inconsistencies in meat quality. Grass-finished cattle are typically lighter in weight, have less fat thickness (FT) and lower marbling scores compared to grain finished cattle of similar age at slaughter (Duckett et al. 2014). To improve live weights and carcass size at slaughter, grass-fed animals tend to be held on pasture longer than cattle held in a feedlot through the finish phase. This increased time on pasture can have a negative effect on meat quality since the animals are older at the time of harvest than feedlot finished animals. Age affects meat tenderness because collagen naturally increases with the age of the animal (Weston et al. 2002; and Duckett et al. 2013). Thus, controlling the age at slaughter could be one method to improve meat tenderness (Kim et al. 2007; Duckett et al. 2014). Aging of the carcass postmortem is another. Duckett et al. (2014), found that aging animals slaughtered at 18.3 months for 14-days postmortem produced tender beef. Moreover, Pordomingo (2006), suggests that an annual ADG of 1.6 lbs./day and an ADG of 1.8 lbs./day in the last 90 days of forage-finishing can produce high-quality beef. Thus, providing forages that meet or exceed the increasing plane of nutrition required during growing and finishing stages promote favorable gains to meet targeted slaughter weights within a desirable age.

Proper nutrition is only part of the equation when it comes to raising grass-fed beef. Selection of animals with genetic qualities that contribute to producing high-quality grass-fed beef, such as marbling score (and growth performance), is an important consideration. Genetics and breed selections should reflect the operational goals and capability of the grass-finish operation. For example, in Argentina, Pordomingo (2006) found a high correlation between marbling ease and medium framed animals raised on grass. Thus, selection of animals for grass-finished beef production in Argentina would likely include this combination of genetics and size. The effect of nutrition on the marbling potential of the finished animal begins in utero during the last half of the gestation and carries through to weaning (Pordomingo 2006). Malnutrition of the cow during gestation, or of the calf while on the dam or at weaning, leads to less adipose tissue development, and subsequently, decreased marbling potential through the finish phase.

In addition to marbling and the presence of intramuscular fat, color is also considered an important attribute of meat quality to the consumer (Henchion et al., 2017) and the first to be considered when making a purchase (Ouali et al. 2006). Myoglobin is an iron and oxygen binding protein which influence the muscle/meat color. Dependent on the state of oxygenation of myoglobin there are three natural colors formed. The lack of, or minimal exposure to oxygen results in deoxy-myoglobin and a deep purple color (Bidner et al. 1986; Muir et al. 1998). Upon exposure to oxygen, myoglobin in the meat is oxidized to form oxy-myoglobin that results in bright red color consumers associate with "freshness" in beef (Muir et al. 1998). By contrast, when meat is exposed to post-mortem conditions that are unfavorable (i.e. acidic pH levels), the iron in the myoglobin is oxidized to the ferric state forming Metmyoglobin. Metmyoglobin is brown in color and unattractive and associated with old meat.

Dark meat color has been considered a common occurrence grass-finished cattle as the result of carcass fat cover, pH and weight (Bidner et al. 1986; Muir et al. 1998; Priolo et al 2001). Post-slaughter the conversion of muscle to meat begins though biochemical pathways. These pathways require energy (ATP) which is provided via creatine phosphate (short-term; 15-30 post-mortem) and glycogen (long-term; 2 hours post-mortem) (Huff-Lonergan et al. 2003).

The process comes to end when glycogen stores are depleted, lactic acid accumulates and pH declines leading to the conversion of muscle to meat (Huff-Lonergan et al. 2003). In addition, pre-slaughter stress has been known to deplete the needed glycogen in muscles to reduce pH post-mortem and can lead to dark cutting meat (Muir et al. 1998; French et al. 2000a; Plessis and Hoffman 2007). Grain-fed animals are more accustomed to handling compared to grass-fed animals thus less prone to pre-slaughter stress than the latter (Priolo et al. 2001; Muir et al., 1998), and consequently, less prone to having dark meat color.

Grazing Behavior

A grazing animal's daily behaviors change in relation to a hierarchy of diet selection and physiological needs (Heitschmidt and Stuth 1991). Diet selection is broadly defined by the landscape in which the grazing animal is foraging, thus different characteristics of landscapes will influence movements of animals and their grazing activity (Heitschmidt and Stuth 1991). Some examples of landscape characteristics are boundaries (i.e. fences), plant community distribution, terrain constraints, the location of water, all of which influence grazing behavior and ultimately, the choice of when, where, and what the animal consumes.

In addition, the physiological needs of the animal influence their grazing behavior. According to Heitschmidt and Stuth (1991), essential physiological needs of the grazing animal occur in a hierarchy of priority that, from highest to lowest, consist of maintaining their water balance, thermal balance, energy balance, predator/avoidance/security, and rest. Since the first essential need of the grazing animal is the maintenance of their water balance, livestock will loiter near water resulting in greater grazing pressure in these areas.

To maintain thermal balance animals will seek areas of shelter, or shade to avoid excessive heat or cold before they choose to graze or forage (Heitschmidt and Stuth 1991). Core-body temperature (CBT) can be used to predict animal performance (Spiers et al. 2004). Increasing ambient temperatures lead to rising CBT until a threshold is reached and the animals thermoregulation behaviors kick in (Spiers et al. 2004). Thermoregulation mechanisms of the grazing animal can cause a nutrient partitioning shift (O'Brien et al. 2009) to maintain homeothermy and this can reduce the production capacity of the animal (Spiers et al. 2004). Heat or cold stressed animals decrease forage intake as they seek to regain their thermal balance and this period of decreased intake may persist after a heat or cold stress bout (Huston & Pinchak, 1991; O'Brien et al., 2009). For example, Spiers et al. (2004) found that dry matter intake (DMI) continued to be depressed three days post-heat stress bout in dairy cows.

Maintenance of a caloric balance is the third priority for grazing animals (Heitschmidt and Stuth 1991). When hungry, grazing animals will consume forages to meet their nutritional needs or until the rumen is filled (Heitschmidt and Stuth 1991). Sprinkle et al. (2000) found that grazing behavior was affected by gastrointestinal tract size such that intake increased with increase in size of the gastrointestinal tract. Additionally, Burns and Sollenberger (2002) showed that the nutritive value of grass was positively correlated with diet selection. This may explain results reported by Aharoni et al. (2013) that looked at foraging activity and pasture condition across seasons. Specifically, they (Aharoni et al. 2013) found that foraging activity depended on pasture condition, and increased from winter to spring as pasture condition increased, but then decreased during summer with declining pasture quality, before increasing again in fall as pasture condition improved.

The fourth priority for grazing animals is orientation and predator avoidance (Heitschmidt and Stuth 1991). The main grazing bouts (GB) observed in ruminants typically occur during sunrise and sunset, with intensity and length greater during sunset GB (Gregorini et al. 2006b). Thus, at nighttime most animals seek shelter from environmental elements and/or areas that allow a clear view of surroundings to watch for predators. Increased GB in late afternoon have also been associated with the higher levels of carbohydrates in the plant that accumulate during the day through photosynthesis (Huntington and Burns 2007). In a study by Burns et al. (2005) cattle fed sunset-harvest alfalfa had greater dry matter intake compared those fed sunrise-harvested alfalfa.

The last or fifth priority is rest, a period when energy cost is minimized, rumination and/or sleep occur. According to Heitschmidt and Stuth (1991), animals will forage away from primary foci, such as water or a bedding ground (thermal balance site), to meet nutritional needs and then return to rest and ruminate consumed forages and/or avoid predators. Once a grazing animal has reached satiety, the site they return to is determined by what physiological need thresholds have not been met (Heitschmidt and Stuth, 1991). According to Aharoni et al. (2013), forage quality can dictate foraging time because as digestibility decreases, gut retention time increases, thus grazing will cease due to a full rumen. Similarly, Heitschmidt and Stuth (1991) state that the time it takes to reach satiety can be dictated by the total foraging time per day which is influenced by forage quality, thermal balance, and the short-term stability of forage supply.

Forage Quality

Forage quality describes the nutritive value of various grasses and forages that a grazing animal consumes. The quality of the forages influences feed intake rates and animal performance. The main plants used by grazing animals are grasses, forbs and shrubs. All of which vary physiologically, nutritionally and ecologically. Grasses are the main feed supply for forage-based livestock production systems. Forage plants contain carbohydrates, lipids, proteins, vitamins and minerals that are essential for animal growth and production. Grazing animals are equipped to convert the consumed forages into useful products such as meat, milk, fiber and other products. Although forage plants provide energy to the grazing animals via carbohydrates, much of the animal's energy is captured through volatile fatty acids (VFA's) that are produced during rumen microbial fermentation (Huston and Pinchak 1991). Proteins provide the amino acids that are used to produce desired tissues (i.e. muscle, bone, wool etc.) or products (i.e. milk) from the animal. Vitamins serve as catalysts for various chemical reactions or metabolic functions in the animals. Similarly, both macro-(required in large amounts) and micro-minerals (required in small amounts) are used for growth of animal tissues and metabolic functions (Huston and Pinchak 1991). The type forage, plant parts consumed, growing conditions, and maturity of the forage can influence forage quality.

Grass types are commonly categorized as warm-season (C4) and cool-season (C3), with their anatomies that lead to different photosynthetic pathways as the primary distinguishing feature. Warm-season grasses are more commonly found in tropical and sub-tropical regions compared to C3 grasses that are more common in cooler temperate zones. About 85% of our feed supply for production of meat, milk and fiber is sourced from C4 grasses in warm-climates (Moser et al. 2004). The Kranz anatomy of C4 grasses contain two distinct types of photosynthetic cells, bundle sheath and mesophyll cells (Berry and Patel 2008). Within the epidermis of the leaf of C4 grasses, the vascular centers are surrounded by bundle sheath cells and these structurs are encased in mesophyll cells (Berry and Patel 2008). This modified leaf anatomy allows for compartmentalization of the important biochemical reactions in the assimilation of CO_2 and greater photosynthetic capacity and efficiencies of C4 grasses than C3 grasses. (Berry and Patel 2008). Specifically, warm-season grasses are water and nitrogen efficient due to the compartmentalization that allows closer proximity and concentration of CO_2 in the bundle sheath cells. This allows for re-assimilation of the CO_2 via Rubisco in the Calvin cycle in addition to reducing photorespiration rates (Ghannoum et al. 2011). The modified anatomy of C4 grasses is beneficial to the plant but can have negative impacts on its digestibility for grazing animals due to a higher fiber content that subsequently affects feed intake rates. Conversly, they can be of high quality (increase digestibility) when grazed early in the growing season before fiber content increases as the plant ages (Coleman et al. 2004). The nutritive quality of C4 grasses declines with maturity, which also occurs with C3 grasses (Coleman et al. 2004), however C4 grasses generally have higher fiber content and lower protein content compared to C3 grasses (Huston and Pinchak 1991) to begin with. In comparison to forbs (legumes) C4 grass will also have a lower digestibility (slow rate of passage) due to greater cell wall components (high fiber). Most legumes are used to improve pasture quality due to their nitrogen fixation capabilities, high crude protein, and low fiber content that improve feed intake rates relative to a grass only diet (Marten et al.1988).

Plant parts that are consumed by the animals will also have varying digestibility. Stems or stalks have higher fiber content than leaves and this decrease digestibility. Consumption of high fiber plant parts causes the rumen to remain full longer resulting in slower feed intake rates (Coleman and Moore 2003; Coleman et al. 2004). Feed intake can also be influenced by palatability of the plant type and parts because they vary in texture, smell, and taste. Leaves typically have greater palatability compared to other plant parts because of their lower fiber and higher protein content.

Leaves are needed for photosynthesis while the roots, rhizomes, and stolons are used as transfer and storage units for photosynthates (carbohydrates) that accumulate during the day

(Coleman et al. 2004). These photosynthates contribute to the growth of the plant. Grasses grow from meristematic tissue located at the base of the plant (Moore et al. 2004). Grazing removes the top portion (leaves) of grasses, therefore, the growth points are left behind and the plants can recover (Moore et al. 2004). Forage quality is higher in grasses during their vegetative stage than in their reproductive phase (Coleman et al. 2004). Leaving leaf material behind when grazing during the vegetative stage allow for adequate photosynthesis for recovery and regrowth of the plant (Moore et al. 2004). Leaf to stem ratios are important determinants of forage quality because young live tissue, such as leaves, are metabolically activity and thus higher quality compared to mature tissues (Huston and Pinchak 1991).

Forage quality can also be influenced by the environment in which the forage plants grow. Changes in ambient temperature, precipitation, and light intensity during the day can alter forage quality. Increased ambient temperature can decrease digestibility of C4 grasses largely due to the maturation of the plants in warmer temperatures (Coleman et al. 2004). Low precipitation is more of concern in C3 grasses compared to C4 grasses due to adaptive leaf anatomy of the latter that allows for efficient water use (Coleman et al. 2004). However, precipitation is important to maintain soil moisture which is essential for plant growth (Silva et al. 2012; Huston and Pinchak 1991). Decreased soil moisture causes plants to allocate stored nutrients to plant growth and once depleted, senescence is likely to occur in different plant parts. According to Silva et al. (2012), proper soil moisture is needed to maintain cell turgor pressures. Plant cell turgor affects photosynthesis, such that higher cell turgor has greater photosynthetic capacity. Photosynthetic capacity that is at or near maximum enables the plant to have a greater leaf to stem ratio and a higher crude protein content. In contrast, slower growth due to water stress may be beneficial in some instances because of less stem elongation and a greater leaf to stem ratio that improves dry matter digestibility (Coleman et al. 2004). In addition to temperature and soil moisture, light intensity influences plant photosynthetic rates and thus has an indirect influence on forage quality. As light intensity increases photosynthetic rates increase up to the light saturation point. The products of photosynthesis, such as non-structural carbohydrates (NSC), accumulate in the leaves, leaf-stem bases, stolon's, roots (Coleman et al. 2004) and corms of the plant (Moraes et al. 2012; White 1973). Non-structural carbohydrates are soluble compared to the less/insoluble structural carbohydrates, cellulose and hemicellulose (Coleman et al. 2004). Warm-season grasses store NSC typically as starch as compared to C3 grasses that accumulate fructans (Colman et al. 2004) and sucrose (Briske 1991; White 1973). According to Haydon et al. (2013), NSC metabolism is regulated by the circadian rhythm and peaks about 4 hours after dawn. Shewmaker et al. (2006) found that the minimum concentrations of NSC occur in early morning while maximum concentrations occur in late afternoon. Decreased light intensity reduces tiller growth, NSC production, and stem elongation (Coleman et al. 2004).

Non-environmental factors can affect forage quality consumed by the animal. Grazing should be timed so that removal of plant parts occurs during the vegetative stage, a time when nutritive quality is high and plant recovery is favorable. Grazing time should be controlled such that some leaf material is left behind to allow photosynthesis to occur for regrowth and accumulation photosynthates once grazing has ceased. The intensity which grazing occurs can also influence forage quality. Grazing intensity refers to the amount of forage consumed over a period (Heady and Child 1994; Holechek et al. 1998). The stocking rate, defined as the number of animal units per unit area per unit of time, is used determine the grazing intensity.

Animal Performance

Animal performance is commonly measured by the animal's average daily gain (ADG; kg/day) over a period. The physiological state (growing, pregnant, nursing) of the animal will influence their nutritional requirements thus their ADG will vary between states. Growing animals (calves, weaners) tend to have greater rate of growth thus ADG tends to be greater compared to their adult counterparts. In addition, animal frame size (small, medium, large) will influence nutritional requirement. It is important to know the different levels of nutrition between the various frame size to ensure that the animals gain weight at an acceptable rate to reach slaughter weight at the desired age. Body size is an important genetic factor that can influence production efficiency of an animal (Aharoni et al 2009; Duckett et al. 2014; Tatum et al. 1986). One method to measure body size is the estimation of frame size. The Beef Improvement Federation (BIF) frame scores are widely used to assign frame size to animals based on hip height and age. Frame scores can be used as a predictor of future weights at slaughter at a given degree of finish (Tatum et al. 1986; Hammack and Gill 2009). In a grass-finish cattle study, Duckett et al. (2014) found that an increase in frame score from small to medium increased average daily gain, body weight, hot carcass weight, and rib eye area. This agrees with other studies that showed that larger framed animals had greater live and hot carcass weights compared to smaller framed animals (Tatum et al. 1986; Plessis and Hoffman 2007). However, larger framed animals have been linked with higher energy cost/demands (Aharoni et al., 2009) and increase in age at slaughter that results in less tender beef (Tatum et al. 1986, Plessis and Hoffman, 2007; Duckett et al., 2014).

Aharoni et al. (2009), found that under conditions of lower forage quality, smaller framed cows were more active and their specific energy cost/demands per activity was lower than larger frame cows. When movement or locomotion is considered, smaller framed animals will use less energy to move compared to large framed animals because of their difference in body mass (Aharoni et al. 2009). Therefore, smaller frame cows were more energy efficient than larger frame cows when the forage quality was low because they can travel further distances and were able to forage more selectively for the same cost of energy that was expended by the larger framed animals. However, Aharoni et al. (2013) also suggests that larger frame cows may have a greater production potential and achieve greater energy intake rates that maintain higher heat production when forage quality is high. Nevertheless, regardless of frame size, a foraging animal when compared to animals in confinement, will have greater energy requirements due to their increase in activity (Aharoni et al., 2013). This change in behavior due to foraging activity, along with environmental conditions, can alter the core body temperatures of the grazing animal (Aharoni et al. 2013; Gebremedhin et al. 2011).

Core-body Temperature

Core-body temperatures that extend outside the normal physiological range for the animal results in heat or cold stress. Heat stress is caused by the inability of the animals to dissipate heat to their surrounding environment (Morrison 1983; Nienaber and Hahn 2007). A common method used to evaluate the environmental impacts on cattle and their ability to exchange heat, especially in warmer climates, is the temperature-humidity index (THI) (Nienaber and Hahn 2007). Normal THI is <74 and an increase above this threshold is an indication of the potential for heat stress in cattle. Cattle have been known to increase standing time with increasing temperature to expose more surface area and dissipate excess heat (Nienaber and Hahn 2007; Gebremedhin et al. 2011). The physiological response of cattle during heat stress is to decrease feed intake since rumination increases metabolic heat production

(Mader et al. 2002). It is also suggested that the decrease in feed intake during a heat stress bout is associated with increased water intake that fills the rumen (O'Brien et al. 2010; Mader and Davis 2004). Decreased nutrient intake is one of the first signs of heat stress that effects production of the animals (Nienaber and Hahn 2007; Mader et al. 2002). O'Brien et al. (2010) evaluated the effects of heat stress in paired, fed calves, and found a decrease in dry matter intake of 12%. Thus, a decrease in feed intake may be a survival-oriented physiological response that animals use to adapt to an environmental stressor such as excess heat (Nienaber and Hahn 2007). In extreme cases, production losses can be coupled with economical losses due to cattle death (Mader et al. 2002). According to Nienaber and Hahn (2007), after the onset of a heat stress bout, animals take about 3-4 days to completely recover from the effects. During recovery animals will engage in compensatory feed intake to alleviate the reduced dry matter consumption during the heat stress bout (Mader and Davis 2004; Nienaber and Hahn 2007).

Materials & Methods

Study Site

This research was conducted at the Mealani Research Station of the University of Hawai`i in Kamuela, Hawaii (20° 2'22.60"N, 155°36'31.73"W) at approximately 800 meters above sea level. The annual average temperature range is between 13.7 to 21.4° C while the relative humidity averages 80.5 – 99.1%. Precipitation at the station averages 1,397 millimeters annually. The entirety of the station encompasses 79.48 hectares, of which 62.73 hectares were in pasture used for raising beef cattle. Kikuyu grass *(Pennisetum clandestinum)* was the primary forage grass in the pastures. Pangola grass (*Digitaria eriantha Steud.*, Stargrass (*Cynodon aethiopicus*) along with several legumes, including white clover (*Trifolium repens*), bird's-foot trefoil (*Lotus corniculatus*), and Kaimi Spanish clover (*Desmodium canum*) were also present. The pastures produced an average of 8343kg dry matter per hectare annually during the study period.

The Station's grazing land is divided into 52 paddocks of approximately 1.21 hectares in size. Each paddock contained individual water sources to provided water *ad libitum* to the cattle. Pasture management practices utilized a "leader/follower", high-intensity, short-duration grazing system. There were three herds in the system; grass-finish cattle, replacement heifers, and the breeding herd. The grass-finish cattle were the lead herd, and thus the first to enter a new, fully-rested paddock. The replacement heifers and breeding herd sequentially rotated into the paddock vacated by the previous herd. Each herd were rotated daily.

Animals and Observations

All animal observations and procedures were approved by the University of Hawai'i-Mānoa Institutional Animal Care and Use Committee (IACUC# 13-1761). Grazing behavior and core body temperatures (CBT) were collected on two cohorts (2013 and 2014) which were randomly chosen from the previous year's calf crop. Each cohort consisted of twenty-four Angus, Hereford, and Angus-Hereford crossed beef cattle composed of twelve steers (n=12) and twelve heifers (n=12). In both years, steers and heifers entered post-weaning into the grass-finish program at an average age of 4.5±0.2 months and 219.4±6.2 kg BW, and 5.2±0.2 months and 210.6±5.7 kg, respectively. Beef Improvement Federation (BIF) frame scores were calculated for each animal at the beginning of each trial by determining hip height, age, and gender (Hammack & Gill, 2009). Body condition scores (BCS) were assessed for each animal at the end of each trial prior to harvest. The cattle were raised and finished entirely on grass with only a mineral supplement provided.

Behavior observations were conducted during three seasons, Fall of 2013 (Sept. - Nov.), Spring of 2014 (June - Aug.), and Fall of 2014 (Sept. - Nov.). Observation periods were conducted on four consecutive days (Day Code;1,2,3,4) during three, two-hour monitoring periods (Period 1, 0700-0900=AM; Period 2, 1100-1300=NOON; Period 3, 1500-1700=PM) on each observation day. All animals were identified with a specific number using All Weather PAINTSTIK® Livestock Marker at the start of each observation period. The numbers allowed observations to be conducted at a distance that would not disturb the herd. Animal behaviors recorded were grazing, walking, standing, standing and chewing, laying, laying and chewing, at water, at mineral/rubbing, running, fighting, mounting/mounted. Behaviors that were less than 5% of the animal's total behavior time were grouped together as "other" behaviors.

Core-body Temperature

Two different types of data loggers were used to monitor core-body temperature during the observation periods (Figure 1). The first was the MaxiDS1922T iButton® Temperature

Loggers (IB) with 8KB Data-Log Memory produced by Maxim Integrated, San Jose, CA The second was the HOBO® Tidbit v2 Water Temperature Data Logger produced by Onset Computer Corporation, Bourne, MA. All loggers were set to record temperatures at one-minute intervals and time was synchronized with Hawaii Standard Time (HST) using the corresponding specific programs for each logger.

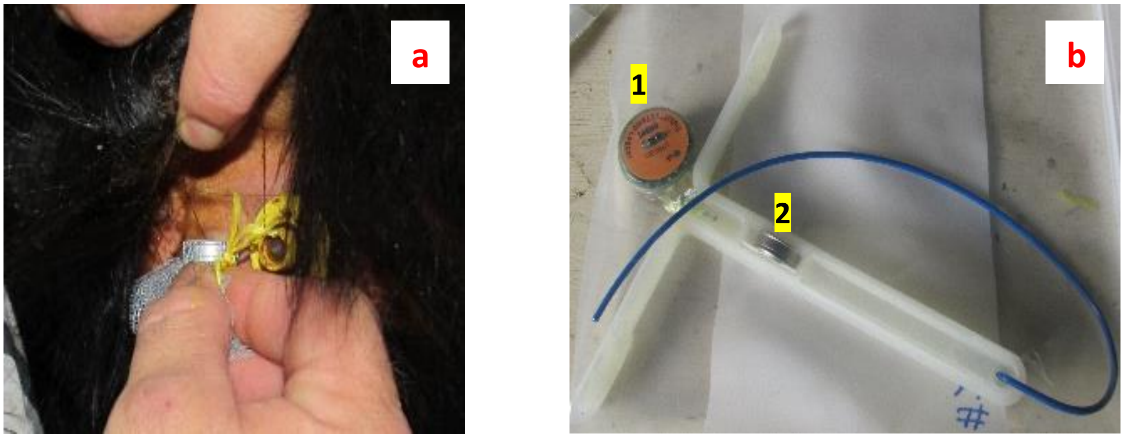

Figure 1: a) iButton wrapped in white mesh netting secure with yellow twine and being placed into ear canal of animal. b) Blank CIDR with attached TidBit (1) and iButton (2).

Ear temperature (ET) was recorded with the iButton logger. Each logger was placed in mesh netting, secured with cotton twine, and then inserted into the base of the ear canal (Figure 1a). The logger was further secured by back-filling the ear canal with cotton gauze. The free end of the cotton twine was tied to the ear tag of the animal. The ear was then wrapped with medical grade cloth tape to prevent dislodgement of the logger.   Steers and heifers were fitted with ear temperature loggers in November 2013 and June through November of 2014.

Vaginal temperature (VT) was recorded with the iButton (VT IB) and TidBit (VT TB) logger. Tidbit loggers were used to recorded VT for all observational months in 2013 (August, September and November) and 2014 (June through November). The iButton loggers were used to record VT in July through November of 2014. The iButton and TidBit was secured in center section of a blank controlled internal drug release (CIDR) device (Figure 2b). The iButton (Figure 1b-2) was fitted into a small hole near the junction of the CIDR arms. No additional adhesive was needed to secure the iButton. The Tidbit (Figure 1b-1) was secured using monofilament tied to the Tidbit on one end and the tip of CIDR where the two arms separate on the other. The CIDR was inserted into the vaginal canal using a standard CIDR applicator. General purpose lube was applied to the applicator tip prior to insertion.

Forage Sampling and Analysis

Forage samples were collected to evaluate production and quality. Samples were collected from the next paddock in the rotation in the morning (AM), noon (NOON), and afternoon (PM) during the herd observation periods in the Fall 2013, Summer 2014, and Fall 2014. Collection of samples from the next paddock prevented disruption of herd's behavior and assured samples were representative of un-grazed forage. Forage was hand clipped to a height of approximately 10 centimeters of residual. Samples were placed in paper bags and dried using a Despatch LBB Forced convection oven (ITW EAE, Minneapolis, MN) at 70°C (~160°F) for approximately 48 hours or until the dry weight was constant. Once dried, samples were ground through a Thomas Wiley Lab Mill grinder (Model 4275-Z15, Thomas Scientific, Swedesboro, NJ), bagged, labeled, and sent to Dairy One© Forage Laboratory in Ithaca, New York for analysis. Thirty-seven different components were assessed to determine overall forage quality. However, only the results for crude protein (CP), acid detergent fiber (ADF), non-detergent fiber (NDF), lignin, water soluble carbohydrates (WSC), simple sugars (ESC) and total digestible nutrients (TDN), macro-minerals; calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), sodium (Na), microminerals; iron (Fe), copper (Cu), manganese (Mn), molybdenum (Mo), and the ratios of Ca:P and Cu:Mo are reported here.

Weather Variables

Relative humidity (RH; %), wind speed (WS; kph), and ambient temperature (T; °C) were recorded at 15-minute intervals during monitoring periods using a Kestrel 400 pocket weather tracker (Kestrelmeters.com, Minneapolis, MN). Photosynthetic active radiation (PAR; μMol m^{-2} s^{-1}) was also recorded at 15-minute intervals using LI-COR LI-250A Light Meter fixed with a PAR Sensor (LI-COR Environmental, Lincoln, Nebraska). Additionally, relative humidity and ambient temperature data recorded at 30-minute intervals was collected from the U.S. Weather Service station (NOAA-NWS, 2015) located on the Mealani Experiment Station. The RH and AT from this recording were used to calculate a daily and monthly temperature-humidity index (THI) during the study periods. The following formula was used for THI calculations:

$$THI=0.8t_{db}+RH\ (t_{db} - 14.4) + 46.4$$

The t_{db} = dry-bulb air temperature (°C) and RH = relative humidity in decimal form (Nienaber and Hahn 2007). Monthly precipitation summaries were provided by the National Weather Service-Weather Forecast Office, http://www.prh.noaa.gov/hnl/pages/hydrology.php, for the Kamuela Upper station located at the study site (NOAA-NWS, 2015).

Animal Performance Measures

Body-Weight Measurements

Body weights (BW) were measured at birth, weaning, monthly at the start of each observation period, and one day prior to harvest. Average daily gain (ADG; kg/day) over the periods between weight intervals were estimated for all animals in the trial. Individual animal ADG from wean-to-slaughter (WS) was also compared to time spent per behavior and mean CBT for each animal.

Carcass and Shear Force Evaluations

All 24 animals were transported to the U.S. D. A. inspected Hawai`i Island slaughter facility one day prior to their respective harvest date. Year one (2013) the animals were harvested in three groups; 1/2/2014 (n=6), 2/6/2014 (n=10) and 2/19/2014 (n=8). In the second year (2014), animals were harvested in two groups on; 12/30/2014 (n=12) and 1/28/15 (n=12). Animal live weights were taken one day prior to slaughter and hot carcass weights were collected at harvest. All carcasses were evaluated following the U.S. Department of Agriculture (USDA) *Standards for Grades of Beef Carcass* (USDA, 2016). Prior to fabrication, a one-inch thick steak between the 12th and 13th rib was collected, individually labeled with animal identification, vacuum sealed and refrigerated for shipment to the Human Nutrition, Food, and Animal Science meat lab at University of Hawai'i at Mānoa, Honolulu. Once received by the meat lab, the steak samples were removed from the packaging and excess subcutaneous fat was trimmed to less than 2mm. The steaks were then repackaged under vacuum seal and aged for two weeks in a refrigerator (-20°C). After the aging period, the steaks were analyzed for tenderness using the Warner-Bratzler Shear Force method described by Wheeler, Shackelford and Koohmaraie (2005).

<u>Statistical Analysis</u>

All data analyses were conducted using Minitab®17 (Minitab 17 Statistical Software, Version 17.3.1 State College, PA: Minitab, Inc.). Analysis of variance (ANOVA) using a general linear model procedure (GLM) were conducted on the data for core-body temperature, forage quality, animal performance and weather variables. The model factors included for CBT, forage and weather variables were season, period, and the interaction of season by period. The model factors for animal performance were cohort, gender, events, and the cohort by gender, cohort by event, gender by event and cohort by gender by event interactions. Tukey's pairwise comparison was used to separate means at $P<0.05$. Regression analysis were used to test for correlations in CBT for: 1) ET between steers (response) and heifers (predictors); 2) Vaginal temperatures between IB (response) and TB (predictor); 3) Heifer ET IB (response) and heifer VT IB (predictor) and VT TB (predictor). The carcass and meat quality measurements were tested for significance between years, gender and year by gender interaction with ANOVA using a GLM.

Stepwise regression was used to identify observed behaviors (predictors) that were the most significant influences on average daily gain (ADG) across the 24 animals in each cohort. The standard stepwise regression procedure adds or removes predictors in each step by comparing the determined alpha-to enter or alpha-to-remove to the p-values in the model. The alpha-to-enter and alpha-to-remove were both set to 0.15, thus any predictor was removed from the model at each step, until all predictors fell within $\alpha=0.15$. The final predictors were included in the model. Data were considered statistical significant when p-value was equal to less than 0.05.

Results

Weather Variables

The effects of season and period on PAR were significant ($P<0.05$) (Table 1) but the season and period interaction showed no significant effect ($p=0.267$) (Table 2). Average PAR in Fall 2014 (642.9±29.6 µMol m^{-2} s^{1}) was significantly lower than that of Fall 2013 (799.5±30.8 µMol m^{-2} s^{-1}) and Summer 2014 (749.3±32.1 µMol m^{-2} s^{-1}). Across all seasons, PAR was significantly greater during the NOON ($P<0.05$) period with an average of 1144.2±32.8 µMol m^{-2} s^{-1} and least during the PM period with an average of 467±22.5 µMol m^{-2} s^{-1}.

Average RH was highest in the Summer 2014 during the AM (85.9±1.2%) and lowest Fall 2013 at NOON (55.3±1.1%) (Table 1). Wind speed varied significantly across seasons, periods and season by period. (Table 1). The highest average WS was in Summer 2014 NOON period (10.1±0.5 kph) and lowest in Fall 2013 AM periods (4.4±0.5 kph) (Table 1).

Ambient temperature varied significantly between periods across all seasons ($P < 0.05$) (Table 1). Average AT was lowest during the AM periods and highest during the noon period across all seasons. The highest AT was recorded 23.5±0.2 °C during the Fall 2013 NOON period. The greatest within season difference in mean AT occurred in the Fall 2013 NOON period (23.5±0.2°C) and AM period (19.5±0.3°C) (Table 1).

Precipitation

Average precipitation (mm) was significantly greater across years ($p=0.022$) but not across seasons or the interaction of year by season. Total precipitation was greater in 2014 (1883 mm) compared to 2013 (858 mm) (Figure 2). Total P for 2013 across all season compared to 2014 (Figure 2). Lower than normal precipitation rates in 2013 can be attributed to the drought conditions in Hawaii during 2013. The greatest precipitation total was recorded in the Spring of 2014.

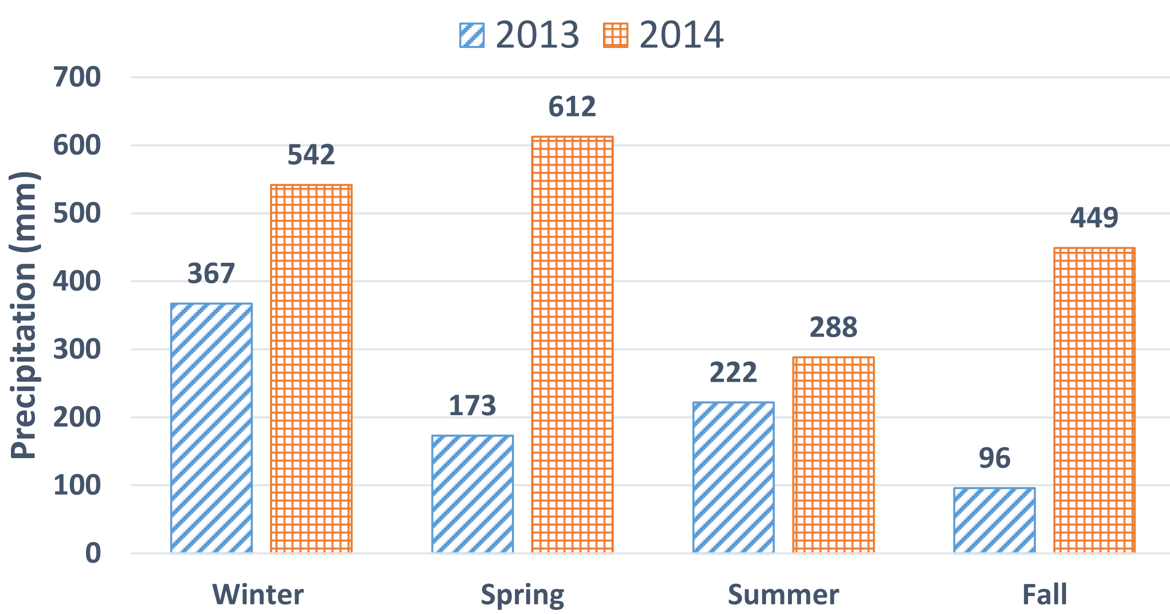

Figure 2: Seasonal cumulative precipitation (mm) at the Mealani Research Station for 2013 and 2014.

Table 1: Mean (±SEM) PAR (µMol m-2 s1), relative humidity (RH; %), wind speed (WS; kph) and ambient temperature (AT; °C) by season and period.

	Fall 2013			Summer 2014			Fall 2014			p-value
Variables	AM	Noon	PM	AM	Noon	PM	AM	Noon	PM	season * period
PAR (µMol m^{-2} s^{1})	606.5 ±35.6^{b}	1239.3 ±47.2^{a}	522.5 ±41.8^{bc}	568.2 ±37.8^{b}	113.1 ±63.7^{a}	540.9 ±40.4^{b}	527.9 ±31.6^{bc}	1062.1 ±57.5^{a}	335.9 ±30.5^{c}	0.267
[n]	[91]	[108]	[108]	[102]	[107]	[107]	[107]	[107]	[107]	
RH (%)	76.1 ±1.1^{cde}	55.3 ±1.1^{g}	69.6 ±1.4^{f}	85.9 ±1.2^{a}	76.5 ±1.4^{bcd}	81.4 ±1.5^{ab}	81.3 ±0.9^{abc}	71.0 ±0.8^{ef}	75.8 ±0.7^{de}	0.0001
[n]	[92]	[108]	[108]	[101]	[107]	[107]	[107]	[107]	[106]	
WS (kph)	4.4 ±0.5^{d}	7.8 ±0.5^{bc}	7.2 ±0.5^{c}	7.8 ±0.5^{bc}	10.1 ±0.5^{a}	9.4 ±0.5^{ab}	6.4 ±0.5^{cd}	7.6 ±0.4^{bc}	6.4 ±0.4^{cd}	0.038
[n]	[105]	[108]	[108]	[108]	[108]	[108]	[108]	[108]	[108]	
AT (°C)	19.5 ±0.3^{e}	23.5 ±0.2^{a}	21.0 ±0.6^{bc}	19.6 ±0.2^{e}	21.6 ±0.2^{b}	20.6 ±0.2^{cd}	19.7 ±0.2^{de}	22.7 ±0.3^{a}	21.1 ±0.2^{bc}	0.0001
[n]	[92]	[108]	[108]	[101]	[107]	[108]	[108]	[108]	[108]	

Means that do not share a letter across a row are significantly different ($p<0.05$).

Temperature-Humidity Index

The effects of year, month, period and their interactions were all significantly different (p<0.05) except for the interaction of year by period (p=0.252). The interaction of year by month by period was significantly different (p=0.0001). The greatest THI was in 2013 October NOON period (64.9±0.1) and lowest 2013 February AM period (57.1±0.2). Average monthly THI was greatest in the NOON period across both years and months (Figure 3). At no point across years did the THI approach the heat-stress threshold of 74 (Figure 3).

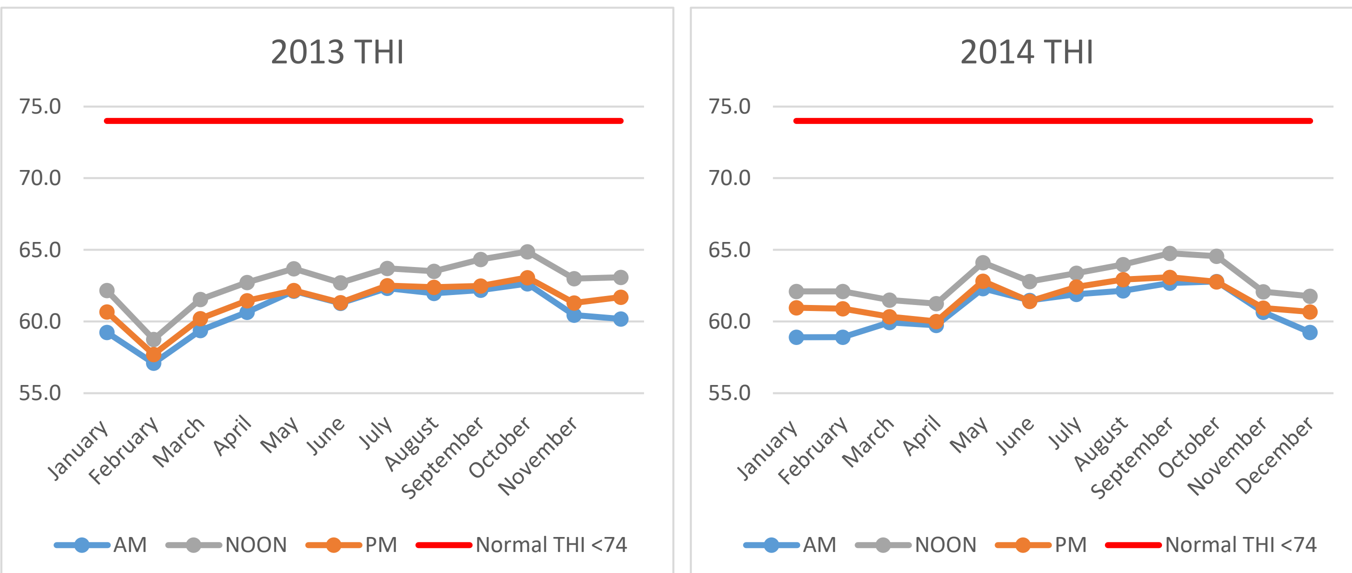

Figure 3: Average monthly temperature-humidity index (THI) values during daily periods (AM, NOON, PM) from 2013-2014.

Forage

Production

Forage production (FP) was significantly greater between years (p=0.007) and the interactions of year by season (p=0.005) but not across seasons (p=0.097). The average FP in 2014 (10525±4562 kg DM/ha) was greater than in 2013 (6711±3480 kg DM/ha). Across years by seasons, 2014 Spring has the greatest FP (12498±3127 kg DM/ha) and the lowest FP was in 2013 Winter (4542±1109 kg DM/ha). The average calculated carrying capacity (AUM/ha) of the grazing area was greater in 2013 (0.35 AUM/ha) compared to in 2014 (0.32 AUM/ha) (Table 2). The change in stocking rate varied seasonally each year depending on the forage demand of the grass-finish animals as they grew in relation to the available forage (Table 2).

Protein & Energy

Effects of year, season and the year by season interaction were significantly different ($p<0.05$) for seven of the components (CP, ADF, NDF, Lignin, ESC, TDN and RFV). However, WSC was only significantly different between periods ($P=0.001$) (Figure 3). Crude protein was lowest in Fall 2013 (14.4±2.4%) and greatest in Fall 2014 (18.7±2.8%) (Table 3). Acid detergent fiber was least in Fall 2014 (33.6±2.6%) compared to Summer 2014 and Fall 2013 that had similar values (Table 3). Neutral-Detergent fiber was least in the Summer 2014 (61.0±4.5%) compared to Fall 2013 (66.3±3.1) and Fall 2014 (64.0±2.6). Lignin content was highest in Fall 2013 (5.6±1.2%) with similar values seen both Summer and Fall of 2014 (Table 3). Total digestible nutrients (TDN) were similar in Summer 2014 (61.6±3.1%) and Fall 2014 (60.1±1.6%) and least in Fall 2013 (57.4±3.5%).

Table 2: Animal weight, Animal Units (AU), Average forage production (FP), Forage Available (FA), Forage Demand (FD), Carrying Capacity (CC) and Stocking Rate (SR) at the Mealani Research Station during the 2013 -2014 Grass-finishing beef trials.

	2013				2014			
	Winter[1]	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Total Animal Weight (kg)[2]	6154	8106	10230	11368	5468	6524	9906	11598
Total AUs (Total Animal Weight/454kg)[3]	13.6	17.9	22.5	25.0	12.0	14.4	21.8	25.5
Forage Production (kg Dry Matter/ha; ±SEM)	*4542 ±1109	11493 ±1065	5673 ±1037	7602 ±1054	4542 ±1109	12498 ±3127	11188 ±1866	9205 ±1024
Forage Available (kg DM ha)[4]	2271	5747	2837	3801	2271	6249	5594	4603
AUM Basis								
Forage Demand (kg DM/month)[5]	4814	6336	7965	8850	4248	5098	7717	9027
Station Carrying Capacity (AUM/ha)[6]	6.4	16.2	8.0	10.7	6.4	17.6	15.8	13.0
Seasonal Stocking Rate (AUM/ha)[7]	2.1	1.1	2.8	2.3	1.9	0.82	1.4	2.0

*FP values estimated from 2014 Winter values.
[1]Seasons; Winter (Dec.-Feb.), Spring (March-May), Summer (June -Aug.), Fall (Sept.-Nov.).
[2]Total animal weight is the sum of the current years cohorts (n=24) body weight taken at the start of each season.
[3]Total Animal Unit (AU) = (Total Animal Weight/454kg)
[4]Forage Available (FA) = (kg DM/ha x 0.5 utilization level)
[5]Forage Demand (FD) = (Total AUs x 354 kg DM/AUM)
[6]Station Carrying Capacity = (FA/354 kg DM/AUM)
[7]Seasonal Stocking Rate =(FD/FA)

Table 3: Seasonal (Fall 2013, Summer 2014, Fall 2014) average (±SD) of crude protein (CP), acid detergent fiber (ADF), neutral-detergent fiber (NDF), lignin, water soluble carbohydrates (WSC), simple sugars (ESC), total digestible nutrients (TDN) and relative feed value (RFV).

Variable	Fall 2013	n	Summer 2014	n	Fall 2014	n	p-value year*season
% CP	14.4±2.4[c1]	98	16.8±2.4[b]	105	18.7±2.8[a]	107	<0.05
%ADF	35.0±1.8[a]	98	35.3±2.3[a]	105	33.6±2.6[b]	107	<0.05
%NDF	66.3±3.1[a]	98	61.0±4.5[c]	105	64.0±2.6[b]	107	<0.05
% Lignin	5.6±1.2[a]	98	3.8±1.2[b]	105	3.8±0.5[b]	107	<0.05
% WSC	6.9±1.9	98	6.9±2.1	105	7.0±2.9	107	0.908
%ESC	5.3±0.9[b]	98	5.4±1.2[b]	105	6.9±2.2[a]	107	<0.05
%TDN	57.4±3.5[c]	98	61.6±3.1[a]	105	60.1±1.6[b]	107	<0.05
RFV	86.7±5.6[c]	98	94.5±8.9[a]	105	91.4±6.2[b]	107	<0.05

[1]Means across a row that do not share a letter are significantly different (p<0.05).

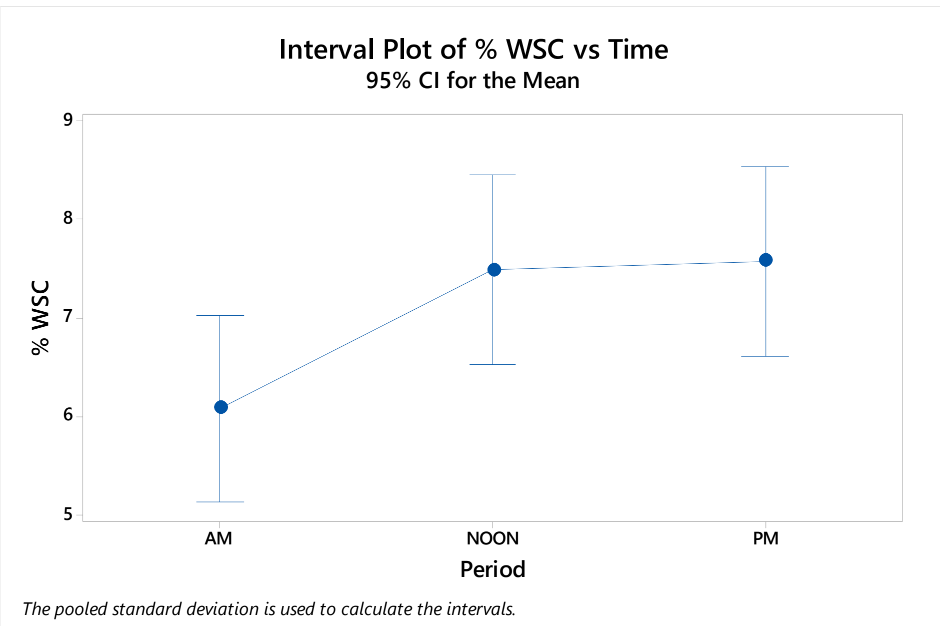

Figure 4 Interval plot of Water Soluble Carbohydrates (WSC) % by period (AM, NOON, PM) across all seasons. The AM (6.3±2.2%) collection time had significantly (p=0.001) lower concentration of WSC compared to NOON (7.3±2.2%) and PM (7.4±2.4%) values.

Macrominerals

Forage macro-mineral (Ca, Mg, P, K, and Na) concentrations varied significantly by season, but not by the period of day (Table 4). Forage calcium concentration was lowest in the Fall 2014 (0.26±0.03%) but similar in Fall 2013 (0.29±0.04%) and Summer 2014 (0.29±0.04%). Magnesium concentrations in Fall 2014 (0.36±0.08%) were significantly higher than those of the Summer 2014 (0.28±0.04%) and Fall 2013 (0.28±0.03%). Forage phosphorus levels were significantly lower in the Fall 2013 (0.23±0.05%) than in Summer 2014 (0.39±0.10%) and Fall 2014 (0.36±0.08%). Potassium (K) levels were highest in the Fall 2014 (3.36±0.54%) and significantly different ($P<0.05$) than levels in all other seasons. Average K levels in Summer 2014 (3.14±0.75%) was greater than Fall 2013 (2.58± 0.50%). Sodium (Na) concentration was significantly greater ($P<0.05$) in the Summer 2014 (0.19±0.15%) compared to the Fall 2013 (0.04±0.04%) and Fall 2014 (0.05±0.06%). The calcium and phosphorus ratio (Ca: P) differed between all seasons ($P<0.05$) with the highest ratio in Fall 2013 (1.3±0.35).

Microminerals (Trace minerals)

Forage iron levels (Fe) differed between all seasons ($P<0.05$). Fall 2013 had the highest Fe concentration with 271.4±124.6 ppm as compared to the Fall 2014 (77.2±30.7 ppm) and Summer 2014 (119.9±90.6 ppm) seasons (Table 4). Copper (Cu) concentrations were significantly lower ($P<0.05$) in Fall 2013 (8.4±1.03 ppm) than both the Fall 2014 (9.2±1.4 ppm) and Summer 2014 (8.9±1.5 ppm) seasons. Forage manganese (Mn) levels differed between all seasons ($P<0.05$) with the highest values found in the Fall 2013 (128.1±22.6 ppm) and lowest in Fall 2014 (75.7±31.5 ppm). Molybdenum (Mo) concentrations were significantly higher ($P<0.05$) in Summer 2014 (0.19±0.09 ppm) forage than in the Fall 2014 (0.15±0.07 ppm) and the Fall 2014 (0.13±0.07ppm). Forage copper to molybdenum ratio (Cu:Mo) was significantly lower (P<0.05) in the Summer 2014 (60.1±30.7) than in the Fall 2013 (75.3±23.3) and Fall 2014 (72.9±26.8) seasons.

Table 4: Seasonal average (±SD) of calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), sodium (Na) and microminerals; iron(Fe), copper(Cu), manganese(Mn), molybdenum(Mo) and the ratios of Ca:P and Cu:Mo.

Variable	Fall 2013	N	Summer 2014	N	Fall 2014	N	p-value
% Ca	0.29±0.04[a1]	98	0.30±0.04[a]	105	0.26±0.03[b]	107	<0.05
%Mg	0.28±0.03[b]	98	0.28±0.04[a]	105	0.36±0.08[b]	107	<0.05
%P	0.23±0.05[b]	98	0.39±0.10[a]	105	0.36±0.08[a]	107	<0.05
%K	2.58±0.50[c]	98	3.14±0.75[b]	105	3.36±0.54[a]	107	<0.05
%Na	0.04±0.04[b]	98	0.19±0.15[a]	105	0.05±0.06[b]	107	<0.05
Fe, ppm[2]	271.4±124.6[a]	98	119.9±90.6[b]	105	77.2±30.7[c]	107	<0.05
Cu, ppm	8.4±1.0[b]	98	8.9±1.5[a]	105	9.2±1.4[a]	107	<0.05
Mn, ppm	128.1±22.6[a]	98	89.2±42.2[b]	105	75.7±31.5[c]	107	<0.05
Mo, ppm	0.13±0.07[b]	98	0.19±0.10[a]	105	0.15±0.07[b]	107	<0.05
Ca:P	1.3±0.3[a]	98	0.8±0.4[c]	104	1.2±0.4[b]	107	<0.05
Cu:Mo	75.3±23.4[a]	98	60.1±30.7[b]	105	72.9±26.8[a]	107	<0.05

[1] Means across rows that do not share a letter are significantly different (p<0.05).

[2]ppm=parts per million

Core-body Temperature

Ear Temperatures Between Steers and Heifers

Across both years ET varied significantly (p<0.05) between genders, season, period and the interaction of these terms. Steer ET was highest in Fall 2014 PM period (39.0±0.7°C) and lowest in Summer 2014 AM period (38.0±1.2°C) (Table 5). The highest ET in heifers was 38.7±0.4°C which occurred in Fall 2013 NOON period and lowest ET was AM period of both Fall 2013 (38.0±0.4°C) and Fall 2014 (38.0±0.4°C). The relationship between ET of steers and heifers were evaluated using a linear regression analysis. There was a significant (P<0.05), positive relationship but low R-sq (27.8%) value (Figure 5).

Table 5: Average (±SD) ear temperatures (°C) of heifers and steers by season and period.

	Fall 2013			Summer 2014			Fall 2014		
Gender	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
Heifer	38.0 ±0.5[f]	38.7 ±0.4[a]	38.6 ±0.4[b]	37.9 ±1.0[g]	38.4 ±0.8[e]	38.6 ±0.6[cd]	38.0 ±0.4[f]	38.6 ±0.5[c]	38.6 ±0.5[d]
[n]	5666	5687	5687	17350	17303	17303	17424	17424	17424
Steer	38.3 ±0.7[f]	38.9 ±0.7[ab]	38.9 ±0.7[b]	38.0 ±1.2[g]	38.6 ±0.9[d]	38.8 ±0.8[c]	38.4 ±0.6[e]	38.9 ±0.7[b]	39.0 ±0.7[a]
[n]	5196	5318	5324	17394	17303	17303	16695	16698	16698

[1]Means that do not share a letter across a row are significantly different (p<0.05).

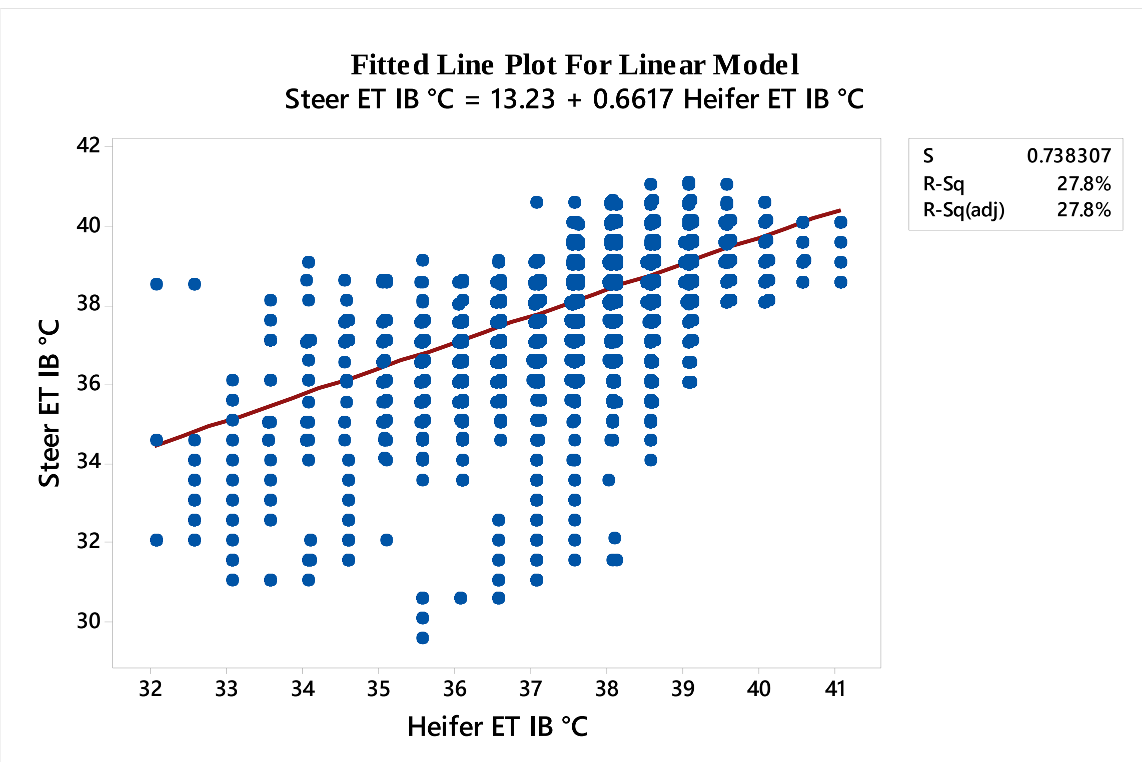

Figure 5: Fitted line plot for linear regression model of the relationship between ET of steers and heifers.

Heifer ET Compared to Heifer VT with TB and IB logger

Ear temperature IB (38.8±0.4°C) and VT TB (38.4±0.7°C) were signifianty different ($P<0.005$). Simple linear regression was used to examine the relationships between ET IB and VT TB and showed a significant ($P<0.05$) postive linear relationshipe (R^2 = 37.8%) however, the S value (0.542) did not give a good indication that this model fit the data well. The average ET IB (38.4±0.7°) was significantly ($P<0.$ 05) lower than VT IB (38.8±0.5°C). A simple linear regression analysis showed a significant ($P<0.005$), positive relationship (R^2 = 27.5%, S=0.664).

Vaginal Temperatures Between Two Logger Types

The heifer VT varied significantly ($P<0.05$) between logger type (IB, TB), season, period and the interaction of these terms (Table 6). Vaginal temperature with the TB logger had a greater variation (8.7) compared to IB (5.0). The VT IB was not measured in the Fall 2013 due to lack of the loggers at start of trial period. The highest VT IB and VT TB occurred in the Summer 2014 PM (39. ±0.4°C; 38.9±0.4°C, respectively). The lowest VT IB was in Fall 2014 AM (38.5±0.4°C) period and lowest VT TB was during Fall 2014 AM (38.4±0.3°C) period. The fitted line regression model showed a significant ($P<0.05$) positive relationship (R^2 = 76.6%) between VT IB and TB, with a low S value (0.22) (Figure 6).

Table 6: Season by period average (±SD) vaginal temperature (VT; °C) with two data loggers; iButton (IB) and Tidbit (TB).

Variable	Fall 2013			Summer 2014			Fall 2014			p-value
	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	
VT IB	-----	-----	-----	38.7 ±0.4^{e}	38.9 ±0.5^{b}	39.1 ±0.5^{a}	38.5 ±0.4^{f}	38.9 ±0.4^{d}	38.9 ±0.5^{c}	<0.05
[n]	-----	-----	-----	11616	11616	11616	12826	12718	12705	
VT TB	38.4 ±0.2^{f}	38.8 ±0.3^{d}	38.9 ±0.3^{b}	38.6 ±0.3^{e}	38.9 ±0.3^{c}	38.9 ±0.4^{a}	38.4 ±0.3^{g}	38.8 ±0.4^{d}	38.9 ±0.4^{c}	<0.05
[n]	16940	16940	16940	16940	16940	16940	13552	13447	13431	

[1]Means across rows that do not share a letter are significantly different (p<0.05).

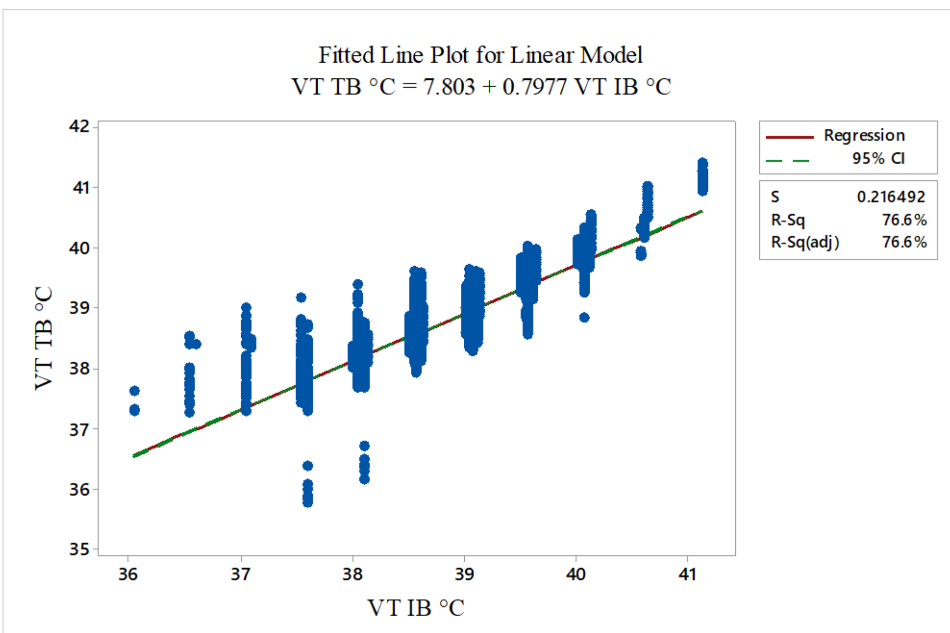

Figure 6 Fitted line plot for linear regression model of the relationship between VT TB and VT IB.

Animal Behavior

Grazing

Seasonally, cattle spent 64.4%, 60.9%, and 64.1% of their time grazing in Fall 2013, Fall 2014, and Summer 2014, respectively. Across periods, NOON time spent grazing was 46.4% and 67.5% in PM period (Figure 7). Heifers time grazing in Fall 2013 was 66.2% while steers spent 59.1% of their time (Figure 8). In the Fall 2014 and Summer 2014 seasons grazing time for heifers was 60.4% and 63.7%, respectively, while steers grazed 61.4%, and 64.5% of their time, respectively (Figure 8). Amongst daily periods (AM, NOON, PM) grazing in the AM was 75.5% for heifers and 75.6% for steers (Figure 9).

Standing

The greatest seasonal difference of time standing was between Summer 2014 (16.7%) and Fall 2013 (14.6%) (Figure 6). Across all periods (AM, NOON, PM) time spent standing was the predominant behavior observed during NOON (Figure 7). In 2013 and 2014 time standing for steers was 20.0%, and 16.5%, respectively and heifers 12.8%, and 15.2%, respectively (Figure 9). Across all season, (Fall 2013, Fall 2014 & Summer 2014) steers spent 20.0%, 15.7%, and 17.3% time standing, respectively, while heifers spent 12.8%, 14.5%, and16.0%, respectively (Figure 8).

Standing while Chewing

Standing while chewing (SC) in Fall 2013 was 6.8% (Figure 6). Across periods SC in NOON period was 7.8% (Figure 7). In Fall 2013 SC time was 9.6% for steers and 6.0% for heifers (Figure 8). In 2013 steers spent 9.6% of their time SC while heifers spent 6.0% of their time. In both NOON and PM periods steers spent 8.6%, and 6.1% SC, respectively, while heifers spent 7.2%, and 5.2%, respectively (Figure 9).

Laying and Chewing

Seasonally, laying and chewing (LC) was greatest in Fall 2014 (12.9%) and least in Summer 2014 (8.3%) (Figure 8). Across periods, LC was greatest during NOON (19.6%) and least in AM (<5%) periods (Figure 7). Similarly, across seasons and periods LC was greatest at NOON (Fall 2013, 25.2%; Fall 2014, 22.4%; Summer 2014, 13.5%) (Figure 8). Laying and chewing was highest Fall of 2014 for both heifers (14.1%) and steers (11.7%) (Figure 6). In all other seasons heifers spent more time laying and chewing compared to steers. Both heifers and steers spent the main percent of their time LC during the NOON period (21.9%, 20.8%; respectively) with no time spent LC in AM. Heifers and steers spent less than 10% of their time LC in PM (Heifer, 8.0%; Steers,7.2%) (Figure 9).

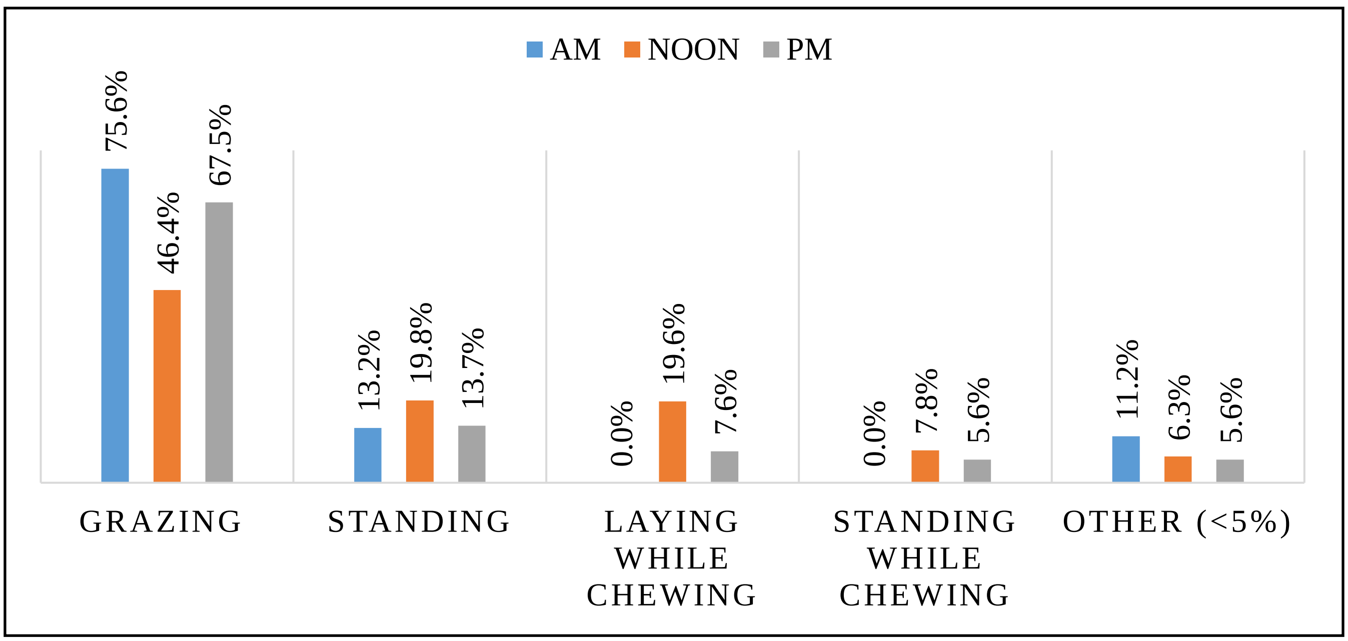

Figure 7: Percent time spent per behavior by period (AM, NOON, PM).

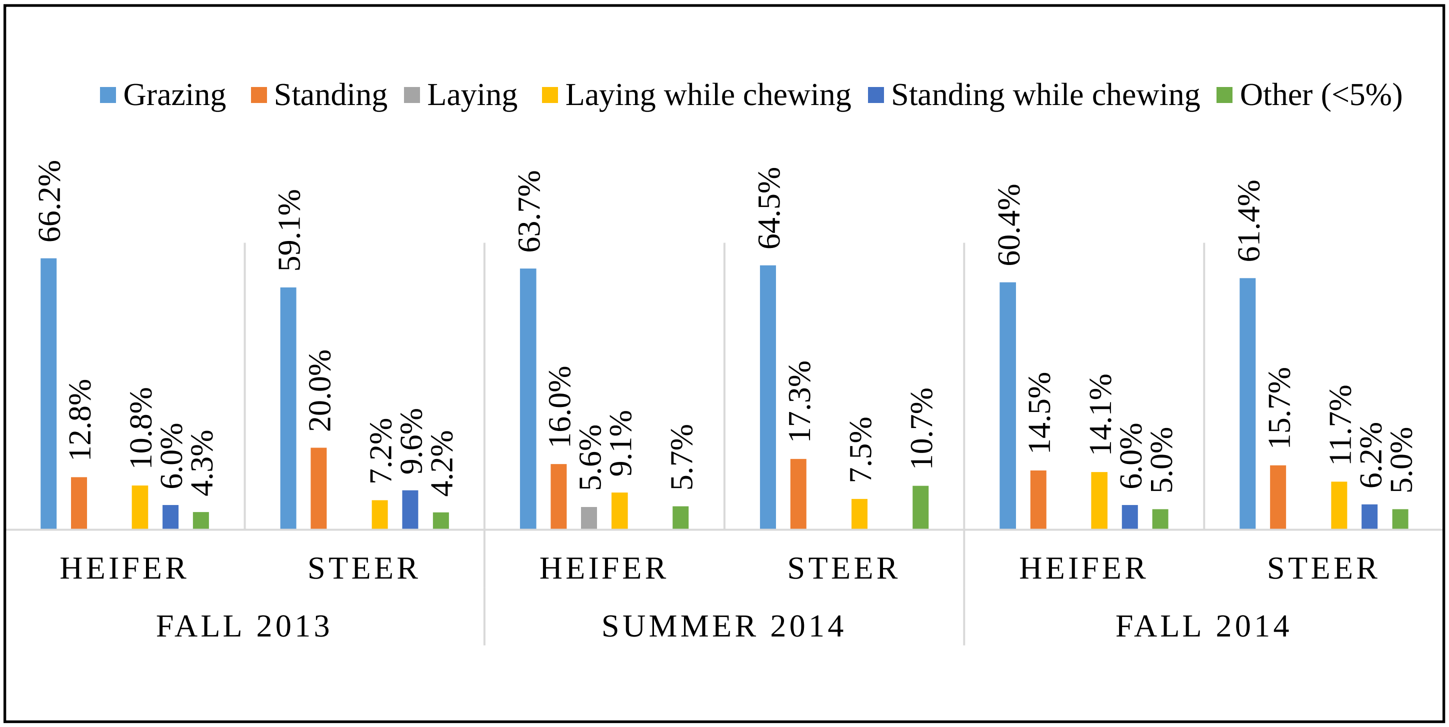

Figure 8: Percent time spent per behavior of heifer and steers by observational year and season.

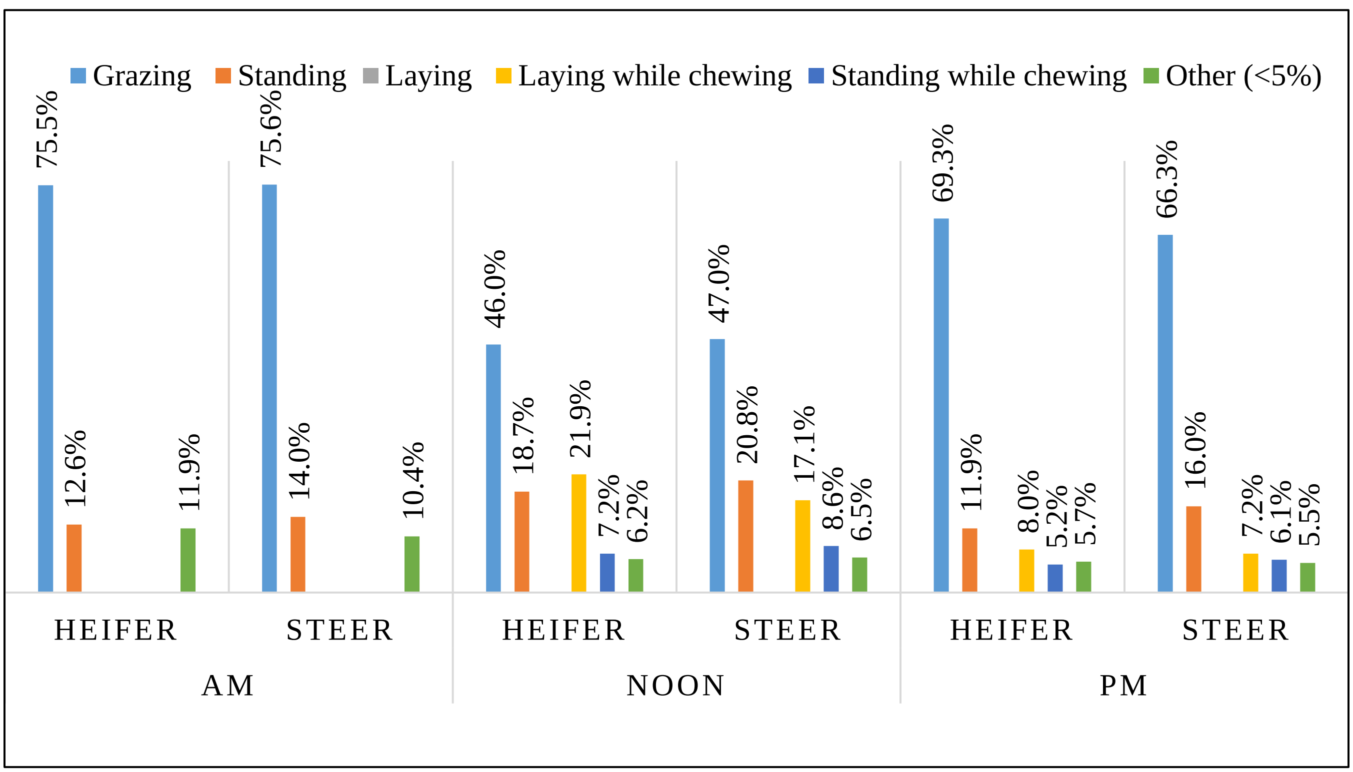

Figure 9: Percent time spent per behavior of heifer and steers by daily periods.

Animal Performance

The ADG was significantly different between genders ($p<0.05$), events ($p<0.05$), year by event ($p<0.05$), and gender by event ($p=0.009$) interactions (Table 7). The year by gender ($P=0.127$) and year by gender by event ($P=0.779$) interactions were not significantly different. The 2013 ADG BW and ADG WS (1.12±0.1 kg/d, 0.61±0.2 kg/d; respectively) was greater compared to 2014 (0.97±0.2 kg/d, 0.70±0.0 kg/d; respectively). Steer ADG BW and WS (1.14±0.1, 0.70±0.1 kg/d; respectively) was significantly greater than heifers (0.95±0.1, 0.62±0.2kg/d; respectively) (Table 7).

Table 7: Average daily gain (ADG; kg/d) between gender by event.

	Heifer		Steer		
Variable	BW	WS	BW	WS	p-value
ADG (kg/d) ±SEM	0.95±0.1	0.62±0.2	1.14±0.1	0.70±0.1	0.009
[n]	[24]	[24]	[24]	[24]	

Step-wise regression analysis revealed that laying while chewing and standing were the most significant behaviors influencing ADG WS (Table 8). The standard deviation had very minimal change from step one to step five while the R-sq. decreased from step one (25.19%) to step 5 (20.40%). Mallows' Cp, which evaluates how well the model fits the data, became closer to the number of predictors plus the constant (1.63) in step five compared to step one (7.00). These statistics together indicate that the predictors in the step five model, laying w/Chewing and standing, were the best predictors of ADG among the variables included in the analyses.

Using this information from our step wise model the regression equation is:

$$\text{ADG Wean - Slaughter} = 1.3190 - 0.000191 \text{ Laying w/chewing Minutes} + 0.000269 \text{ Standing Minutes}$$

Table 8: Step-wise regression analysis of average daily gain from wean to slaughter and time spent for six observed behaviors (grazing, laying, laying with chewing, standing, standing with chewing and others) across both study year, 2013 and 2014.

	Step 1		Step 2		Step 3		Step 4		Step 5	
	Coef	P	Coef	P	Coef	P	Coef	P	Coef	P
Constant	1.3401		1.3404		1.3232		1.2976		1.319	
Grazing	0.00044	0.287	0.000049	0.445	0.000046	0.242	0.00047	0.228		
Laying	0.000313	0.483	0.000336	0.034	0.000358	0.41				
Laying w/chewing	-0.00039	0.032	-0.00038	0.205	-0.00036	0.036	-0.00031	0.052	-0.00019	0.122
Standing	0.000159	0.281	0.000177	0.565	0.000142	0.254	0.000184	0.107	0.000269	0.004
Standing w/chewing	-0.00019	0.549	-0.00018							
Other	0.000202	0.664								
S		0.190		0.188		0.186		0.186		0.187
R-sq		25.19		24.84		24.23		23.02		20.4
R-sq (adj)		14.24		15.89		17.19		17.77		16.86
R-sq (pred)		0		2.47		5.36		6.48		9.25
Mallows' Cp		7		5.19		3.52		2.19		1.63

α to enter = 0.15, α to remove = 0.15

All animals from the study were slaughtered at an average age of 20.7±0.2 months with an average live body weight of 527.1±9.0 kg. Marbling score between gender (P=0.219) and the year by gender interaction (P=0.536) were not significant (Table 9). Combined, marbling score was significantly greater (P=0.045) in 2014 cohort (515±17) than in 2013 cohort (460±21). The year by gender interaction for Fat thickness (FT) was significantly different (P=0.05). Heifer FT in 2013 and 2014 (0.76±0.7, 0.65±0.04 cm; respectively) was significantly greater compared to steers (0.46±0.5, 0.55±0.04 cm; respectively).

Table 9: Mean (±SEM) of carcass and meat quality measurements by year and gender.

	2013		2014		
Variable	Heifer	Steer	Heifer	Steer	p-value
Slaughter Age (mo) [n]	20.6±0.3 [12]	20.1±0.2 [12]	21.1±0.3 [12]	21.2±0.3 [12]	0.499
Live Weight (kg) [n]	499.2±12.7[bc] [12]	543.1±14.6[ab] [12]	487.8±7.5[c] [12]	578.4±21.8[a] [12]	0.129
Carcass Weight (kg) [n]	261.8±5.3[b] [12]	282.2±7.8[ab] [12]	264.9±5.7[b] [12]	308.2±9.3[a] [12]	0.121
Dressing Percent (%) [n]	0.53±0.01 [12]	0.52±0.01 [12]	0.54±0.01 [12]	0.54±0.01 [12]	0.894
Numeric Marbling Score[2] [n]	468.3±37.2[a] [12]	451.7±20.8[a] [12]	540±21.7[b] [12]	490±23.9[b] [12]	0.536
Fat thickness (cm) [n]	0.76±0.07[a] [12]	0.46±0.05[b] [12]	0.65±0.04[c] [12]	0.55±0.04[d] [12]	0.055
REA (cm2) [n]	73.7±2.4 [12]	75.27±2.4 [12]	74.7±2.9 [12]	77.2±2.5 [12]	0.866
WBSF (kg) [n]	4.05±0.14 [4]	4.35±0.62 [7]	4.55±0.46 [4]	4.29±0.30 [8]	0.575

[1]Means across rows that do not share a letter are significantly different (p≤0.05).
2Numeric Marbling Score; Slight=300, Small = 400, Modest = 500, Moderate = 600

Carcass weight (CW) was significantly different between years (P=0.05) and gender (P<0.05) but the year by gender interaction (P=0.121) was not (Table 17). The mean CW of 2014

(286.6±7.0 kg) was greater compared to 2013 (272.0±5.1 kg). Across both years CW of steers (295.2±6.5kg) was significantly greater compared to heifers (263.4±3.8kg). The mean REA and WBSF were not statistically different in any of the comparison made (Table 9).

In 2013, 75% of the animals graded Choice or higher while in 2014, more than 90% of animals graded Choice or higher (Figure 10). In 2013 heifers and steers had a similar percent (75%) of animals that graded Choice or higher. Of the 75% that graded Choice or higher in the heifers, 8.3% were graded low Prime and high Choice compared to steers in which the highest grade was low Choice (25%) (Figure 11). In 2014, all heifers graded Choice or higher compared to only 83.3% of steers that graded Choice or higher.

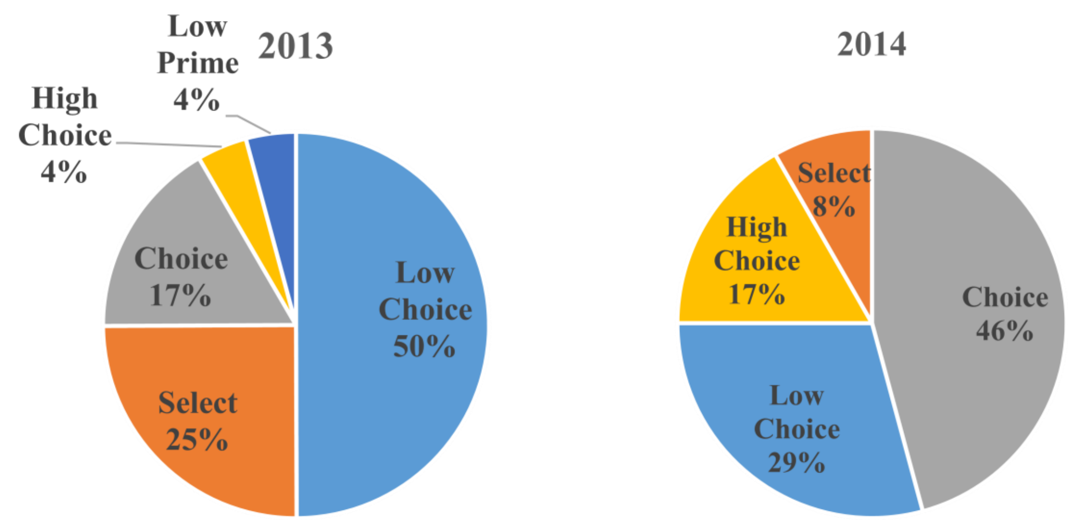

Figure 10: Percent per carcass quality grade for 2013 and 2014.

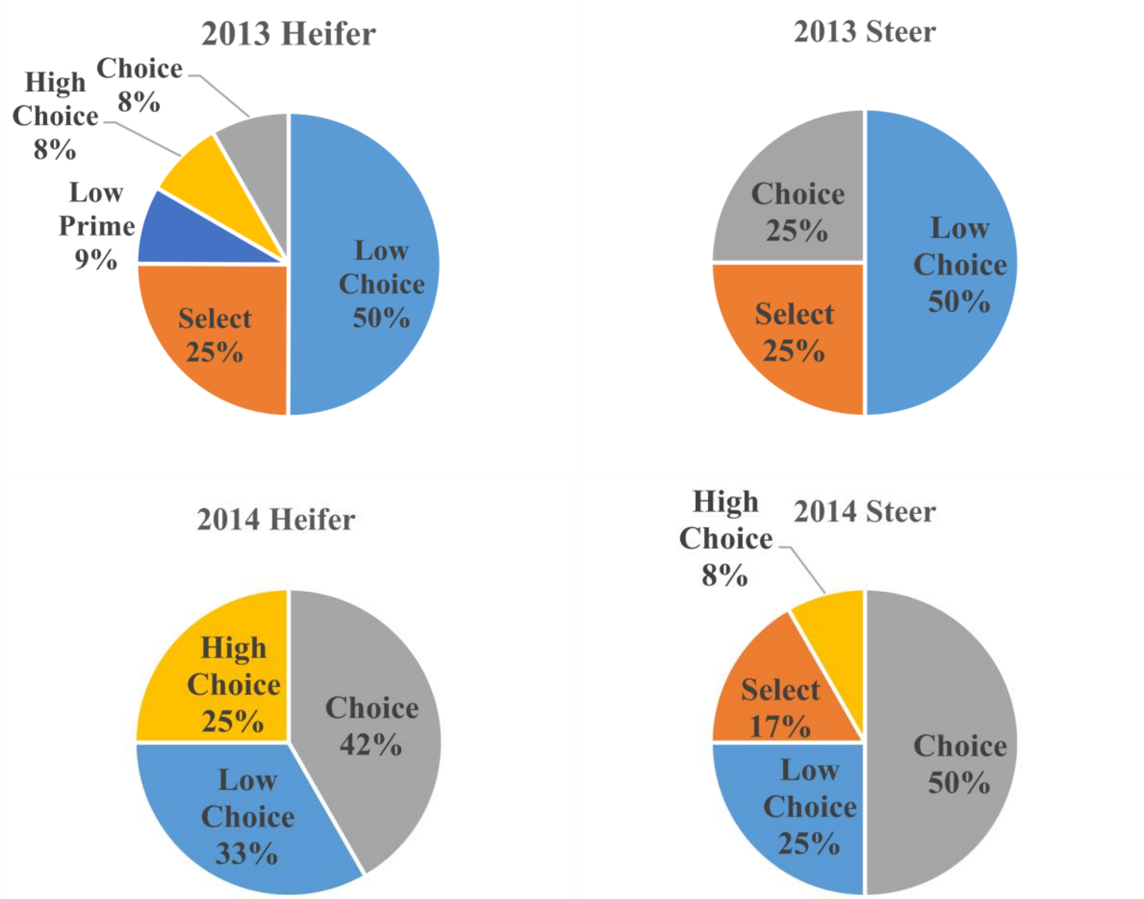

Figure 11: Percent per carcass quality grade by year and gender.

Frame scores for both 2013 and 2014 were calculated using BIF guidelines (Hammack & Gill, 2009) at an average day of age of 575 (±2) days for both 2013 and 2014. Animals were categorized into small (Frame score <4), medium (Frame score 4.1-5.5) and large (Frame score > 5.6) frames. Similar frame scores were seen in both 2013 (5.8±0.2) and 2014 (5.8±0.2) and more animals were of large frame across both years. Frame size between genders in 2013 were similar but heifers had 33.3% more large framed animals compared to steers (50.0%). The number of large frame animals was similar for heifers and steers in 2014. However, 8.3% of heifers were small framed while there were no small framed steers in 2014.

Body-condition scores (BCS) were taken prior to slaughter to in both 2013 and 2014 and were significantly greater (p=0.005) in 2014 (6.5±0.4) compared to 2013 (5.9±0.8). The BCS were not significantly different between frame size (p=0.153), genders (p=0.262), or the interaction of year by gender (p=0.821).

In 2013 amongst the animals that graded Select, 30% were of large framed heifers and 50% were of medium framed steers (Table 10). Fifty percent of the low Choice carcasses were from large and medium framed heifers and steers. The Choice graded animals were comprised of 50% medium framed heifers and 50% large framed steers.

Table 10: Percent of animals per carcass quality grade for 2013 and 2014 by gender (Heifer, H; Steer, S) and frame size (Small, Sm; Medium, M; Large, L).

Year	2013				2014					
Frame Size	M		L		Sm		M		L	
Gender	H	S	H	S	H	S	H	S	H	S
[n]	[6]	[6]	[10]	[2]	[1]		[2]	[3]	[9]	[9]
Low Prime			10%							
High Choice			10%		100%		50%		11%	11%
Choice	50%			50%				33%	56%	56%
Low Choice	50%	50%	50%	50%			50%	33%	33%	22%
Select		50%	30%					33%		11%

The 2014 study animals graded between high Choice and Select (Figure 10). The Select graded animals were both steers, one large and one medium frame. The Choice graded animals were 55.6% large framed heifers and steers and one animal was a medium framed steer. Low Choice graded animals were from both large (Heifer, 33.3%; Steer, 22.2%) and medium (Heifer, 50.0%; Steer, 33.3%) framed animals. More heifers (25%) graded high Choice compared to steers (8.3%, large frame) and included large, medium and small framed animals.

Discussion

Weather & Climate

Weather in Hawaii is characterized by warm temperatures, high humidity levels, and seasonally variable precipitation patterns typical of tropical climates. Air temperature declines with increasing elevation at a rate of 6.5°C per 1000 m (3.5°F/1000ft) (Ahrens 2013). However, there are occurrences of temperature inversions, known as trade-wind inversion (TWI) in Hawaii (Giambelluca et al. 2013), that cause temperatures to increase with an increase in elevation (Ahrens 2013). The TWI in Hawaii typically occurs at about 2200 m (7200ft) above sea level (Giambelluca et al.2013). Below the TWI layer the mountains of the Hawaiian terrain create valleys, ridges and slopes that influence the air flow. Northeasterly trade-winds, a common island feature, cause an orographic effect that moves warm moist ocean air across windward (North and Eastern end) coasts and up slope causing cooling of the moisture-rich air. The cooling of the moisture-rich air increases the relative humidity (Ahrens 2013). This causes greater precipitation on the windward areas as compared to the leeward areas (South and West end) of the islands. Above the TWI layer the increase in temperatures causes a decrease in relative humidity and a decrease in precipitation rate (Gaimbelluca et al. 2013). Average precipitation is greatest during the months of October through April due to winter storms, while the summer and early fall months (June – September) are dryer. These factors combined have an important influence on forage production in Hawaii's rangelands.

Fukumoto et al. (2015) identified two zones of different elevation range and rainfall that promote forage production suitable for high-quality grass-finished beef: the HI WET zone lies between 610 – 1372 m (2,000 – 4,500 ft.) and has an average annual rainfall greater than 762 mm (30 in.) per year, and the LO WET zone found below 610m (2,000 ft.) in elevation with an annual average rainfall greater than 1270mm (50 in.) per year. Our study site was located in the leeward side of the HI WET zone at an elevation of 800 m. Total precipitation at the site in 2014 (1883 mm) was significantly greater compared to 2013 (858 mm). Thus, our study site was well within the HI WET suitability zone for high-quality grass-fed beef production.

In addition, mild seasonal ambient temperatures and relative humidity represented a thermal neutral environment for cattle at our study site. The THI heat stress threshold for livestock occurs at 74 (Nienaber and Hahn 2007). Heat stressed animals may exhibit decrease dry matter intake and other physiological responses such as panting to dissipate heat (Morrison 1983). Results showed that THI generally increased from the AM to Noon period before decreasing again in the PM period. While this daily variation in THI was consistent across the months the relative magnitude varied with the lowest THI values occurring in the winter months and higher THI values observed in the summer months. Importantly though, at no time during 2013 and 2014 did THI exceed 65. Consequently, the climate during this study was, at no time, thermally stressful for the beef cattle on trial. According to FASS (2010) thermal neutral environment minimizes energy expenditure for the animal.

Forage Quality

Pasture forages vary in quality and quantity depending on type (grasses, forbs or shrubs) climate and growth stage. In warmer climates, C4 grasses make up 85% of the feed supply for production of meat, milk or fiber (Moser et al. 2004). The primary forage type in our study site were C4 grasses. At the end of 2013 the state of Hawaii was coming out a prolonged drought that lasted well over 5 years, and in in 2014 FP was 36% greater compared to 2013 as a function of the higher rainfall. Seasonally, FP increase from Winter through Fall across both 2013 and 2014.

Photosynthetically active radiation (PAR) is intercepted and absorbed by the leaf of a plant. The leaf arrangement, spatial density and distribution of leaves effects how efficient the plant utilizes PAR (Silva et al., 2012). In this study PAR was significantly different between seasons with the highest average PAR observed during the summer and lowest in the winter. Similar seasonal variation was found in several studies (Lara and Pedreira 2011; Silva et al. 2012). There is a positive relationship between PAR and dry matter production (Gobbi et al. 2009; Silva et al. 2012). A greater accumulation of stem and dead material occur when leaf canopy becomes sufficient to intercept 95% of incident PAR (Carvalho et al. 2007; Silva et al. 2012). This leads to increased NDF and decreased digestibility (Huston and Pinchak 1991; Van Soest 1994; Silva et al. 2012).

Neutral detergent fiber and ADF represent the fiber content in forages. Neutral detergent fiber measures primarily the bulk fiber of the cell wall fraction of the plant. Acid-detergent fiber is a measure of the cellulose and lignin content of the plant. Both NDF and ADF increase with age of the plant (Pordomingo 2006; Silva et al. 2012). The relative amount of NDF and ADF in the forage has a close correlation with intake (Silva et al. 2012). Ruminants are foregut fermenters and consequently digestion of plant fiber occurs in the rumen. This fermentation and digestion process is a function of the relative amounts of NDF and ADF. High NDF values create greater gut fill and high ADF slows the digestion. Digestibility is often calculated using ADF while NDF is used to predict intake potential of forages. Consequently, a large fiber content in the forage will decrease daily intake. In our study, seasonal differences were seen in ADF and NDF. Acid detergent fiber was similar in Fall 2013 (35.0±1.8) and Summer 2014 (35.3±2.3) and lower in Fall 2014 (33.6±2.6). Neutral detergent fiber was significantly different across all seasons and was highest in Fall 2013 (66.3±3.1). According to Huston and Pinchak

(1991) C4 grasses typically have higher NDF levels compared to C3 grasses. Pordomingo (2006) suggests that high quality forages for finishing cattle should have an NDF of below 40% and ADF of less than 25%, but this is not typical of C4 grasses. Van Soest (1994) suggested that NDF values above 60% may limit forage intake. However, the animals in our study spent 64.4% of their time grazing during the Fall 2013 when NDF was highest (value). The animals in our study also spent 19% of their time ruminating (laying while chewing and standing while chewing) in the Fall of 2014 when ADF was the least (33.6±2.6 %).

Crude protein (CP) is an important nutritional component of forage, and represents the total protein available. According to Coleman and Moore (2003) CP serves two functions, supply of nitrogen for rumen microorganisms, and amino acid supply for use by the host animal. In our study, across both years, CP was significantly different in all seasons and was 23% greater between Fall 2013 to Fall 2014. There was smaller increase in CP between Summer 2014 to Fall 2014 (10.2%). Crude protein requirements, along with other nutrients, are important during the growing stage of animals. Animal weight, age, gender and desired ADG are all factors that determine CP requirements. The NRC (2010) recommends 11.2% CP for growing steer and heifer calves weaned at a body weight of 227 kg. In our study, across both years, the steers and heifers weaned at 215±4 kg had an ADG of 0.85±0.2 kg/d on forages providing an average of 16.6% CP. Pordomingo (2006), suggests that an annual ADG of 0.73 kg/d is needed to produce high-quality beef on forage.

Plant energy is stored as non-structural carbohydrates (NSC) as either water soluble (WSC) or ester soluble (ESC) carbohydrates. Several studies have shown that increased total NSC is associated with higher dry matter digestibility (Huntington and Burns 2007; Sauve, Huntington and Burns 2009). In our study, WSC did not differ between seasons but were significantly different between daily periods with the highest levels observed in PM (7.4±2.4%). Many studies have found a preference in ruminants for PM harvested forage associated with increased total NSC (Burns et al. 2005; Fisher et al. 1999, 2002; Huntington and Burns 2007; Sauve et al. 2009) and increased dry matter intake (Burns et al. 2005; Huntington and Burns 2007). By contrast, we observed a larger portion of time grazing in the AM period (when WSC was lowest) even though WSC values were higher in the PM. However, the increase in time spent grazing in the AM may have been influenced by the management practice of moving herds into new paddocks each morning.

Total digestible nutrients (TDN) were significantly greater in the Summer 2014 (61.6±3.1%) compared to other seasons. This suggest that overall forage quality was better in the Summer compared to Fall. However, precipitation in Summer 2014 was 44% greater compared to 2013, which can influence forage production and thus overall quality (Silva et al. 2012). According to NRC (2010) a growing steer/heifer weighing 227 kg requires minimum TDN of 63% for ADG greater than 0.68 kg/day, these requirements were not met across both trial years. Yet our trial animals averaged 0.85 kg/day gain perhaps as a function of the 5.4% higher CP than needed (11.2%). In addition, the low stocking rate across both years lowered grazing pressure such that animals could selectively graze higher quality forages.

Minerals

Mineral deficiency can lead to poor animal performance, and although forage grasses can often have adequate levels of minerals it is their bioavailability that is important. Comparing the mineral values in our study to NRC (2010) recommend values for a 227 kg growing steer/heifer all were sufficient apart from Ca and Na. Calcium averages were below recommended levels across all seasons which in turn led to inadequate Ca:P ratios. Calcium and phosphorus are important constitutes of bone growth and thus skeletal development as well as other bodily functions. Calcium also plays a role in post-mortem protein degradation of skeletal muscle and has a large influence on tenderization of meat (Koohmaraie & Geesink 2006). Compared to Summer, forage calcium levels were lower in both Fall seasons and 2014 was lower than 2013. These trends in forage calcium levels may explain the trends in WBSF values we observed.

Sodium is important for regulation of pH as well as proper function of the nervous and muscular systems. Forage sodium levels were not adequate in both Fall seasons. However, all animals in the study were provided with free-choice mineral supplementation which likely corrected any imbalances as no muscular, skeletal or developmental abnormalities were observed.

Microminerals imbalances are common for copper, zinc and selenium (Spears, 2003). Copper deficiency commonly occurs in beef cattle and may be the result of antagonist interference of iron (Fe), sulfur (S) and molybdenum (Mo). Excess Mo and S leads to the formation of thiomolybdates as a byproduct of a reaction with ruminal sulfides that then combine with indigestible solids. These thiomolybdate compounds decrease bioavailability of copper to the animal (Spears, 2003) by reducing available binding sites for copper absorption. The NRC (2010) recommendations growing/finishing animals consume at least10 ppm Cu. The forages in our study averaged 8.8±1.3 ppm Cu and thus did not meet these levels and consequently were deficient. Copper deficiency can be distinguished by the discoloration of the hair coat to a brassy brown color in black cattle or a yellowing in red coated cattle. This was in fact observed our study animals during the spring and late fall seasons. Additionally, the forages across both years, and in all seasons had Fe levels (153.1±121.5 ppm) well above the recommend levels (50 ppm) for growing/finishing (NRC 2010) and at time greater than 200 ppm that is the threshold for antagonism with Cu uptake in the rumen.

Core-body Temperatures

Steers had a consistently higher ET compared to heifers However, the regression model explained only 27.8% of the variation between heifer and steer ET. Our results suggest therefore, that heifer ET or steer ET should not be used as proxy for CBT for each other. Hahn (1990) found under moderate conditions (10±7°C) diurnal differences in tympanic(ear) temperate varied as much as 1.2°C and greater sensitivity to ambient temperatures compared to vaginal or rectal temperatures. Thus, the high variability observed in the ET of heifers and steers could be explained by the responsiveness of loggers to ambient temperatures.

This study found a strong positive relationship (R^2 = 76.6%) in VT between the IB and TB data loggers and is represented by the equation: VT TB °C =7.803 + 0.7977 VT IB °C. Using this model, a predicted VT TB can be found given the VT IB. This could prove useful in comparing data from different studies using these two logger types. Although, it should be noted that the TB logger had a greater range of VT compared to IB that may be explained by the physical characteristics of the TB logger. Because of its size, the TB logger was attached to the CIDR in a manner such that it would be suspended in the vaginal canal and consequently, may have had less contact with tissue than the IB. Hillman et al. (2009) found that heifers can move and change the orientation of temperature loggers inside of the vaginal canal and in some instances, expel them. This behavior was observed in the heifers in our study and may explain some variation in data for both IB and TB loggers. For example, some heifers in this study were observed with a protruding CIDR into the posterior of vaginal canal and additionally, some CIDR with attached loggers were found dislodged. Lowered temperatures could be recorded when loggers are near the posterior of vaginal canal (Lee et al. 2015) or when laying down (Vicker et al. 2010), pushing loggers posteriorly. However, it is not clear whether the heifers were able to expel the CIDR or of it was pulled out by a pasture mate as there was evidence of bite marks on the tail of the CIDR's.

Ear temperature and vaginal temperature between heifers did not show a strong correlation for either logger type. The ET IB and VT TB had a R^2=38.7% which was greater than ET IB and VT IB (R^2=27.5%). Our results contrasted with Bergen and Kennedy (2000) who found a correlation of R^2=0.77 for vaginal and tympanic temperatures. They found that spikes in ET without elevated VT was indicative of an ear infection caused by the reaction of the body to the foreign object in their ear canal and thus removing the data set that represented an ear infection improved correlations. Upon removal of ET loggers in our study there were, at times, an apparent odor and in some instances additional ear wax or cerumen build up on logger packs. In such cases an ear infection was assumed but not medically verified. Since the ear infections were not medically verified we did not screen for high relative ET values that might be the result of an ear infection. However, it was noted that the average ET was greater compared to VT and thus closer evaluation of data and subsequent removal of any data indicative of ear infection may improve correlations per Bergen and Kennedy (2000).

Animal Behavior

The predominant daily behaviors of animals in our study were grazing, standing, standing while chewing, laying and laying while chewing. Animals in our study spent a minimal amount of time (<5%) in other activities drinking water, playing, running and consuming mineral. Kilgour et al. (2012) reported behaviors as primary behaviors (standing, laying stern ally and laying laterally) with the addition of secondary behaviors that could be performed simultaneous with primary behaviors.

Studies show that grazing animals have two major bouts of grazing during the day, in the early morning and mid-late afternoon (Gregorini et al., 2006b), in which grazing is longer and more intense in the evening periods (Gibb, Huckle, & Nuthall, 1998; Huntington & Burns, 2007). The animals in this study spent a greater percent of their time grazing in the AM compared to PM. However, this is likely a reflection of the management of the animals as they were moved to a new paddock each morning just before observations began. Length of grazing bouts in addition to grazing intensity can also lead to greater DM intake values, thus longer grazing bouts may not always be reflective of total captured DM intake. Although we did not measure grazing intensity in our study, we observed, anecdotally, what appeared to be higher grazing intensity in the PM than in other periods. We thus recommend future studies consider grazing intensity as in additional measure of grazing behavior. Gregorini et al., (2004) found that the photoperiod was a strong stimulus for diurnal grazing patterns in beef heifers. They also suggested that grazing was more intense in the later part of the day (Gregorini et al. 2008) which may have been a function of greater digestibility of the forage due to the increase in carbohydrates (Fisher et al. 2005; Sauve et al. 2009; Valente et al. 2013) as well as an increase palatability (Provenza et al. 1998).

Standing while chewing and laying while chewing were behaviors associated with rest and most predominate during the midday or noon period. The feeling of satiety can be linked to the expansion of rumen which sends intrinsic signals to the hypothalamus of the animal causing grazing to cease. It is likely that the stoppage of grazing and the initiation of rest in our study animals was associated more with satiety as no evidence of heat stress in our animals were noted (physical signs and THI < 75), which can also cause grazing to cease.

Animal Performance

Pordomingo (2006) suggests that heifers should finish quicker compared to steers, with better marbling and greater fat cover. In our study marbling score was not significant between genders but the 2014 cohort had a 11% improvement in marbling score compared to the 2013 cohort. According to Pordomingo (2006) effects of marbling begins before birth and carries though calving and weaning. Fat thickness was significant across cohorts and genders and the 2013 cohort of heifers had the greatest fat thickness. Improved forage production and quality from 2013 to 2014 likely influenced the 2014 cohort carcass quality such that 90% of the animals graded choice or better. The ADG was significantly greater in steers from WS compared to heifers. However, across both years, heifer BW ADG was greater than steers.

Behaviors, in terms of energy, can either be consuming (energy negative) or productive (energy positive). Forage animals have a greater energy expenditure as compared to those in confinement due to the increase in locomotion (Aharoni et al. 2013). Brosh et al. (2006) suggested that locomotion during grazing has an energy expenditure of 8.5 to 16.5 % above maintenance levels. Consequently, we could conclude that grazing would be energy negative behavior, while standing, laying, and laying while chewing are energy positive behaviors. Our study found that ADG had a significant positive correlation (R^2=20.5) with time spent standing and laying while chewing when together. Brosh et al (2006) found correlation improved in the stepwise models with the inclusion of forage variables (biomass and chemical composition) in addition to the activities (behaviors). Consequently, we could have improved our correlation (R^2) values had we included our forage variables. Additionally, Brosh et al. (2006) included distance traveled to improve their model of the factors affecting ADG. Aharoni et al. (2009) found that increased activity was observed under conditions of lower forage production. Further, Aharoni et al. (2009) also found that small framed cows were more energy efficient compared to large framed animals. It is possible that our current model of ADG could be improved by including different forage variables, frame size, and distance traveled in a stepwise regression analysis.

Conclusion & Implications

There were no significant effects of CBT on animal behavior in thus study. The study area provided a thermal neutral environment for the animals that never exceeded the THI threshold. The study area was also within the HI WET zone identified by Fukumoto et al (2015) suitable for grass-finished beef production. The large mountainous terrain of Hawai'i island guides our trade winds to bring moisture rich sea air to be cooled at the higher elevations and provides the need precipitation to produce quality forage. The seasonal variability in precipitation can alter forage production and thus, management should take this variability into consideration when allocating animals to pastures.

Forage quality was generally greater during the periods of greater precipitation and warmer temperatures. However, when forage production or their components do not meet the nutritional requirements of the cattle, adjustments to the stocking rate can alleviate some of those challenges. Across both years, despite the lower TDN values, CP was consistently above required levels and consequently, the ADG among our trial animals was within the recommended range suggested by Pordomingo (2006). In a study by Kim et al. (2012) Hawai'i pasture-finished cattle had similar post weaning ADG (0.88 kg/day) compared to mainland feedlot-finished beef that originated in Hawai'i. In addition, to adjusting stocking rate, supplementation of minerals in areas where forages have known deficiencies can prevent or correct any imbalances before abnormalities occur within the cattle.

Management and nutritional needs of the animals were the likely drivers for animal behaviors in our study. Grazing time was greater in the AM periods when animals were moved to new paddocks and least during the NOON period. Standing and laying while chewing was found to be the most influential on ADG from the period of wean to slaughter. Locomotion can lead to an energy expenditure of up to 16.5% above maintenance levels (Brosh et al. 2006), thus behaviors that minimize movement of the bulk of body mass could be energy positive behaviors that result in greater gains. Forage quality may also be a driver for animal behavior because it is the primary method for grass-fed animals to meet their nutritional requirements. Grazing was greatest in Summer 2014 accompanied by least amount of time in ruminating behaviors which may reflect higher digestible forages during this period.

Body size is another important genetic factor that can influence production efficiency of the animal (Tatum et al. 1986; Aharoni et al. 2009; Duckett et al. 2014). The study animals across both years were of medium and large frame, except for one small frame heifer in 2014. According to Duckett et al. (2014) the increase of frame size from small to medium increases ADG, body weight, hot carcass weight, rib eye area. However larger framed animals have greater nutritional requirements compared to their smaller counterparts (Aharoni et al. 2009). In addition, they are typically older at slaughter which can have negative impact in meat tenderness (Tatum et al. 1986; Plessis and Hoffman 2007; Duckett et al. 2014). In our study carcass quality varied between frame size, such that animals that graded choice were of both medium and large frame size. Aharoni et al. (2009) suggest that small frame cows are more active compared to their large frame counterparts, however they are more energy efficient in terms of locomotion allowing them graze selectively on higher quality forage. When selecting animals, matching frame size to the production system, forage available, and slaughter endpoint can be beneficial for the producer.

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